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Transportation Research Record 1792

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Foreword

The 2002 series of the *Transportation Research Record: Journal of the Transportation Research Board* consists of approximately 650 papers selected from 2,000 submissions after rigorous peer review. The peer review for each paper published in this volume was coordinated by the sponsoring committee acknowledged at the end of the text; members of the sponsoring committees for the papers in this volume are listed on page ii. Many of these papers were presented at the TRB 81st Annual Meeting in January 2002, and draft versions were included in the Annual Meeting CD-ROM.

Additional information about the *Transportation Research Record: Journal of the Transportation Research Board* series and the peer-review process appears on the inside back cover. All volumes of the 2002 *Record* series also will be released on a single CD-ROM available for purchase in early 2003.

The Transportation Research Board appreciates the interest shown by authors in offering their papers and looks forward to future submissions.

Sustainable Transportation

U.S. Dilemmas and European Experiences

Elizabeth Deakin

The approach to sustainable transportation issues in the United States was examined in light of findings from a study of sustainable transportation planning in Sweden, Germany, the Netherlands, and Scotland. In the European countries, reducing greenhouse gases has been the initial motivation for most sustainable transportation initiatives, but broader social, economic, and environmental concerns now figure into the idea of sustainability. In the United States, barriers to greenhouse gas reduction and planning for sustainability include uncertainty about the problem and the best ways to address it, uncertainties about public support, and the lack of a clear mandate for action. Nevertheless, efforts are under way locally in the United States to promote sustainable development, and transportation plays a central role in these plans. The European organizations visited are using many of the same strategies as are U.S. planners, but supporting their efforts are strong policy commitments, government incentives, and new planning processes emphasizing collaboration and performance measurement. Tracking the comparative success of these efforts would be an important next step.

Concerns about the sustainability of development practices are increasingly being voiced in the United States, Europe, and other developed countries as well as in the developing world. Early discussions of sustainable development focused largely on environmental damage (especially global warming) from land development and transportation, but increasingly, disparities in economic development and in the choices available to different nations and social groups for housing, jobs, services, and overall quality of life are among the matters of concern. Although the current administration has rejected the Kyoto Protocol, efforts are under way to find other ways to reduce greenhouse gases, and concern about broader quality-of-life issues remains strong.

Interest in sustainable development is motivated by a number of factors. There is a desire to reduce carbon loading of the atmosphere to avoid or reduce the impact of the greenhouse effect and its possibly catastrophic global consequences. There is also worry about a host of other environmental harms, ranging from the effects of deforestation on ecosystems and biodiversity to the impacts of fishery depletion on seacoast economies and ocean health. In both developed and developing countries, the effects of growing dependence on the automobile, rapid urbanization, and sprawl development are major motivations for considering sustainability. In addition, there is interest in maximizing the productivity of infrastructure investment and controlling costs. Desires to preserve farmland, wild land, and other open spaces and to improve urban amenity, redevelop brownfields, and make the suburbs more interesting are additional factors in current discussions. Finally, the social equity of current patterns of consumption domestically and internationally, the necessity of economic growth and development in the less-developed nations, and the relative contributions of the haves and the have-nots to environmental damage and to its potential restoration are additional issues that have entered into the debate over sustainable development.

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OVERVIEW OF PROPOSALS

Proposals that aim to promote sustainable development are as wide ranging as are the problems that motivate them. They include carbon taxes and fuel pricing strategies, new fuels and new vehicle technologies, strategies to phase out fossil fuel power generation, and industrial strategies focusing on efficiency gains. They also include local and regional growth management and urban revitalization efforts, transit investments, and traffic calming programs. The umbrella is wide enough to cover such U.S. federal and state programs as brownfields initiatives, Enterprise Zones, Location-Efficient Mortgage experiments, and Livable Communities programs, as well as programs to promote the use of recycled materials in construction and reconstruction, to implement intelligent transportation systems (ITS), and to formulate new processes of context-sensitive design.

In the United States and other developed countries, transportation is a major focus of sustainable development inquiries, for the simple reason that transportation is so prominent in the many problems that sustainable development aims to address. The United States produces some 30% of the world's total greenhouse gas emissions; transportation accounts for 25% of those emissions. Strategies that do not address transportation would fail to address a large share of total emissions.

Specific transportation measures that have been proposed in sustainable development discussions include the following:

- Electric and other alternative-fueled vehicles;
- High-efficiency gasoline, diesel, and hybrid vehicles;
- Traffic operations and logistics improvements using information technologies and ITS;
- Deployment and promotion of alternative modes such as rail freight transportation and transit, biking, and walking for personal transport;
- Land use strategies that reduce automobile dependence by focusing development on transit and in pedestrian-oriented areas;
- Land use strategies that shorten trips and encourage transit use, walking, and biking through compact, higher density, mixed-use development; and
- Telecommuting and other telecommunications substitutions for travel (*1*).

Although interest in these strategies is high, barriers to their successful implementation also are substantial. Technological alternatives are costly, take time to deploy, and do not always perform well.

social systems would be able to adapt easily. Some system changes appear to be under way already, including increased global mean surface temperatures and rising sea levels (*4*).

In response to this potential threat to social, economic, and environmental well-being, a series of international conferences have been held to develop a plan of action. The Kyoto Protocol, hammered out in 1997, aimed to be step toward the reduction of greenhouse gas emissions over the next decades. The protocol sets out targets for industrialized nations, averaging out to about 5% below 1990 levels by the period of 2008 to 2012. For the United States, the target level was proposed to be a 7% reduction, a difficult target to meet considering that emissions have continued to grow each year. In contrast to most advanced industrial states, the U.S. Congress did not ratify the agreement, however, leaving the United States comparatively uncommitted to action. Subsequently, the current administration also rejected the protocol, while continuing to look for other ways to address greenhouse gas issues.

Finding ways to achieve significant reduction in greenhouse gas emissions in the United States is a major challenge. The largest energy user in the world, the United States is also the largest emitter of CO_2, currently accounting for almost one-quarter of the total. The CO_2 emissions in the United States come from transportation activities, residential and commercial activities, and industrial processes in roughly even shares. Transportation activities in the United States, which have been estimated to be the largest single source of greenhouse gas emissions in the world (*5*), include both motor vehicle emissions and other transportation emissions (e.g., from jet aircraft); however, surface transportation alone is 25% of the U.S. total. Three-quarters of that 25%, about 16%, are from motor vehicle use.

Debate continues over the range of options that might be used to reduce greenhouse gas emissions. Market approaches, regulation-mandated changes in technologies, and restraints on energy use are all under discussion. Reductions need not be targeted proportionally at the various sectors producing CO_2. Indeed, in the short run, developed countries might pay for technological improvements, or perhaps for forest preservation, in less-developed nations as a more cost-effective alternative than immediate technological change or demand suppression at home. Still, many analysts believe that a multipronged strategy will be necessary both to accomplish the needed reductions and to ensure a modicum of equity. Meanwhile, in the U.S. transportation sector, CO_2 emissions are expected to nearly double by the middle of the next century unless technological changes are vigorously introduced or demand is sharply curbed. Either type of reduction could have large economic, social, and environmental consequences far beyond its greenhouse gas effects; hence, research is needed on possible strategies, impacts, and implementation pathways (*6*).

TRANSPORTATION STRATEGIES FOR REDUCING GREENHOUSE GAS EMISSIONS

Table 1 presents a partial list of strategies for reducing greenhouse gas emissions in the United States, identified in the literature and in interviews with transportation officials and academics (*2*). The strategies are grouped into categories based on the component of the transport system addressed: vehicles, roadways, operations, or demand.

The first category of strategies would reduce greenhouse gas emissions through technological change in vehicles and fuels. In the short run, this would most likely be accomplished by improving the efficiency of conventional vehicles, and in the longer run through the introduction of new vehicle technologies and new fuels. Innovations emerging from manufacturer innovations could be put to use in reducing greenhouse gas emissions, for example. If, due to demand-side incentives or changes in public attitudes, consumers began to demand vehicles that are low emitters of greenhouse gases, suppliers would probably respond by offering consumers that choice. Alternatively, the government could provide incentives to manufacturers to produce low-emissions vehicles, or it could mandate the same through regulatory interventions. Corporate average fleet efficiency (CAFE) standards, research and development partnerships, taxes, rebates, and subsidies are specific options to consider, and they could apply to passenger vehicles and trucks both.

A second category of strategies to reduce greenhouse gas emissions would involve improvements to roadways and vehicle operations. Again, different approaches might be used in the short run and over the longer run. Conventional traffic flow improvements such as traffic signal timing, ramp metering, flow metering, and bottleneck removal all have the potential to reduce greenhouse gas emissions by smoothing the flow of traffic and reducing fuel-wasting stop-and-go travel. Driver education could reduce emissions by training drivers to avoid heavy accelerations and decelerations and to be mindful of the fuel consequences of high speeds. Scheduling trips outside of the peak periods could reduce congestion and thereby cut emissions.

Improved methods of accident and incident management and improved logistics and fleet management, both relying increasingly on advanced technologies for vehicle location and communication, also have substantial promise for increased efficiency of operations. Information technology–enhanced routing and scheduling can reduce the fuel needed for transport of both passengers and freight. Technological innovations currently under development offer the potential for significantly larger gains. They include the more advanced aspects of intelligent transportation system improvements such as smart highways and smart vehicles.

Demand management is a third category of strategies for reducing greenhouse gas emissions. Several subcategories of demand management are in use: modal substitution, telecommunications substitution, pricing, and land use strategies all can be thought of as forms of demand management.

Modal substitution means, for example, replacing car trips with transit, paratransit, ridesharing, biking, and walking for personal travel and substituting rail for truck and air freight. Such substitution can be accomplished by providing better modal options (offering services and improving their quality to attract travel to alternative modes) or through incentives for the use of the alternative modes (e.g., subsidies for users of preferred modes). Regulatory requirements (e.g., trip reduction ordinances requiring employers to obtain commute mode shares of no more than 50% by drive-alone) are also a possible way to induce modal substitution.

Telecommunications substitutions for travel also can be considered a form of demand management. Telecommuting, teleshopping, teleconferencing, and distance learning are varieties of telecommunications substitutes for travel.

Pricing incentives and disincentives could be used in the short run to reduce demand and encourage the use of alternative modes or the substitution of telecommunications for travel. In the longer run, vehicle technology improvements would likely be induced by the higher prices. Gas tax increases are the pricing strategy most commonly used in the United States and abroad; fees and taxes that affect vehicle ownership, such as sales taxes and registration fees, also are common. Variations that base taxes and fees on fuel efficiency, emissions, and expected vehicle life could specifically target the reduction of green-fixed route bus service in low-density areas where the service is little used: emissions and fuel use per passenger carried can be higher than would occur by using automobiles or taxis to serve the trips. Hence, the issue is whether market niches cans still be found to which these strategies might effectively be applied.

For some of the strategies, many people would respond that there are indeed more markets to be served. For example, traffic signal timing and other operations improvements are in common use, but many localities have lacked the resources to upgrade equipment or to retime their signals on a regular basis. They could benefit from a funded traffic signal management program. Similarly, few localities have had the resources to fully implement bicycle networks, pedestrian improvements, and traffic-calming programs, and funds for such strategies are oversubscribed. Transit operators and ridesharing service providers often have lists of unfunded improvements. Few have even begun to explore the possibilities for shuttle services, subscription buses, and other innovations. Not all of these strategies would necessarily be cost-effective from a greenhouse gas reductions perspective, but some surely would be.

Other strategies remain in the early stages of deployment and a strategic effort to implement them might produce meaningful results. This is the case, for example, for many of the strategies involving advanced technologies for highway and transit operations. It also may be the case for certain vehicle and fuel technology strategies, in which the wider implementation of experiments and demonstration projects could be useful.

Land use strategies have recently begun to capture the attention of many interest groups, and studies and small programs to test these strategies' transportation effectiveness are under way. Here, too, wider experimentation and systematic evaluation could be useful.

Pricing strategies are still highly controversial in most parts of the country, although some local governments and private operators are successfully managing parking pricing. Also, projects with variable tolls and value pricing are under way in a handful of U.S. highway facilities. Proposed gas tax increases, fee-bates, emissions fees, and other measures have been evaluated in major studies, but so far implementation has not occurred, owing to concerns about equity and opposition to any strategy that looks like a tax. Nevertheless, there is enough interest in these strategies to consider a larger effort toward their implementation than has occurred to date.

How effective would the various transportation strategies be in reducing greenhouse gas emissions? TRB investigated this topic in a 1997 report (*1*). Four scenarios were tested. One emphasized demand management and land use planning, the second focused on improvements in vehicle efficiency, the third emphasized fuel price increases, and the fourth assumed the introduction of new vehicle technologies. Evidence was drawn from the literature on modeling studies and field experiments, and estimates of greenhouse gas reductions were produced for each scenario. The results, which are for the United States, were as follows:

- From aggressive demand management and land use planning strategies: 6% reduction by 2020 and 15% by 2040;
- From a 1.5% annual increase in average new vehicle fuel efficiency: 15% to 20% reduction by 2020 and 35% by 2040;
- From higher fuel prices amounting to a 3% increase per year: 20% reduction by 2020 and 40% by 2040; and
- From the introduction of new low-emissions vehicles (5% of fleet by 2020 and 35% by 2040): no significant change by 2020, and a 30% reduction by 2040.

Even if one assumes that these results are approximately correct, no one strategy by itself offers a silver bullet for the greenhouse gas emission problem. Furthermore, considerable uncertainty about implementation feasibility is connected to each of the scenarios, strengthening the conclusion that thorough consideration of the full range of options is a prudent approach.

KEY ISSUES ON TRANSPORTATION AND GREENHOUSE GAS REDUCTIONS

U.S. interviews revealed several key issues that may block or slow action on transportation strategies for greenhouse gas reductions: uncertainties about the nature and severity of the greenhouse gas problem, lack of agreement on the extent to which transportation strategies should be used in attacking greenhouse gas concerns, uncertainties about the effects of change in transportation technologies, and uncertain public support for intervention. Interview respondents noted that these issues reflect, and are reflected in, the lack of federal mandate and funding for greenhouse gas reduction activities.

Uncertainties About the Problem

Important uncertainties remain about the nature and severity of the greenhouse gas problem. Although most scientists agree that the Earth is warming, there is less agreement about specific mechanisms, including the role of the oceans and forests in carbon absorption and recycling. Furthermore, changes in activity in both developed and developing countries must be predicted to estimate carbon loading of the atmosphere. The pace of development and the choices made could greatly affect such forecasts. Uncertainties, coupled with the high stakes involved, make it hard to muster the political support needed for action.

Unresolved Responsibility for Reduction of Greenhouse Gas Emissions

Analyses often assume that transportation would aim to reduce greenhouse gases proportional to the transportation sector's contributions. However, this is not necessarily the most efficient or effective way to reduce the emissions. As noted earlier, reductions in greenhouse emissions could be obtained by helping developing countries limit or reduce their production of greenhouse gases (emissions trading). Or a higher than proportional share of U.S. reductions might be sought from other sectors of the economy, for example, power generation (accounting for about 36% of total U.S. emissions).

Either strategy raises its own set of concerns about equity, costs, and timing. There appears to be no simple solution that would alleviate all pressure for change in the transportation sector.

Technological Change and Its Implications

Technological advances in the automotive industry and other sectors of the economy have considerable potential to reduce greenhouse gas emissions and, for that matter, other externalities that are broader concerns about sustainability. Aggressive technology deployments, whether in the form of changes in conventional vehicles or through

TABLE 2 Strategies for Sustainable Development

Land Use and Community Development:
Preservation, Rehabilitation, and Redevelopment of Central Cities and High Density Inner Suburbs
Infill in Cities and Suburbs - increased Density, Mixed Use
Reusing Brownfields, Recycling Buildings
TODs and PODs as the Paradigm for New Developments
Quality of Life: Attention to Crime/Schools/Services/Amenities
Recycling/Precycling/Composting Programs
Transportation:
Access vs. Mobility – Basic Concepts
Bike- and Pedestrian-Friendly Cities
Transit, Paratransit, Ridesharing
Telecomuting/Teleconferencing
New Technologies for Improved Efficiency: Electric Vehicles, Traffic Control Systems, Transportation Information Systems
Prices and Subsidies Aligned with Sustainability
Housing and Other Building Designs:
A Range of Choices
Energy-Efficient Buildings
Edible Landscaping
Natural/Indigenous Plants
Business/Job Creation:
Business Leadership
Community Economic Development
Clean/Safe Technologies
Social Equity:
Aligning Taxes and Subsidies with Sustainable Development
Equitable Distribution of Resources

and practitioners and to more closely examine these countries' experiences. Each country is part of the European Union (EU), which provides a consistent overall framework for action; key features of EU environmental policy, enunciated in the Treaty of Rome and Single European Act, are as follows:

- Use a precautionary principle: better prevention than cure;
- Do early consideration of environmental effects;
- Avoid resource exploitation that causes significant damage: use but do not abuse;
- Avoid spillovers in other countries;
- Use a polluter-pays principle;
- Promote a worldwide environmental policy;
- Improve scientific knowledge on the environment;
- Share responsibilities for environmental actions;
- Assign responsibility for action to the appropriate level of government—as close to citizens as possible; and
- Conduct environmental education.

Within that framework, however, considerable variation among the countries was noted. The sections that follow discuss shared approaches in the four countries visited; Table 3 through Table 6 list specific strategies being used by each of the four countries.

Definitions of Sustainability

All of the countries visited use some variation of the Brundtland definition of sustainability—meeting the needs of the present without compromising the ability of future generations to meet their own needs—as the starting point for their efforts on sustainable development. The reduction of CO_2 is an important objective. However, sustainability is seen as a much broader concept having economic and social as well as environmental dimensions. Sustainable development is viewed as development that improves the standard of living and quality of life, while at the same time protecting and enhancing the natural environment and honoring local culture and history.

In this context, sustainable transportation is safe, of high quality, accessible to all, ecologically sound, and economical. It is also a positive contributor to regional development. Specific goals for sustainable transportation include improvements in service quality, safety, air quality, water quality, noise reduction, protection of habitat and open spaces, and historic preservation; the reduction of carbon emissions; and the attainment of local goals consistent with the overall objective.

Policies and Practices

The policies and practices used to pursue sustainability recognize the importance of collaboration, both as a means of reaching agreement on specific goals and objectives and as a way to pursue specific strategies. Each of the countries visited uses collaborative strategic planning to identify and evaluate ways to move toward sustainability and to devise performance measures for assessing progress. Collaborations involve the different levels of government, various agencies, citizens, and the private sector.

Both the EU and each country back the commitment to reducing CO_2 emissions through the use of policies for accomplishing that end. At the same time, they recognize that local governments and the general public typically have more immediate transportation concerns, including mobility needs as well as noise, speeding, and traf-

TABLE 5 European Strategies for Sustainability: Scotland (Edinburgh)

Overall Strategies for Sustainability:
- Regional strategies for development and transport; integrate transport and land use
- Central city vitality
- Public transport competitive and attractive
- Compact and contiguous suburban development
- Emphasis on exchange, not movement

Examples of Sustainable Development and Sustainable Transport:
- Travel Wise program – try to educate public – think before you travel, chain trips, walk or bike, etc.
- Extensive green lane system for bus priority
- Parking pricing
- Car club experiment
- Traffic calming
- Bike streets, bike ways
- Wider sidewalks (also good for business)
- Lower speeds in some zones
- Speed enforcement by camera
- Recycled materials in construction

fic problems. However, initiatives to address local concerns often reduce CO_2 emissions as well, thus contributing to a larger sustainability strategy. European policies therefore encourage and reward such local initiatives. Practices include the following:

- Offer local governments incentives for aligning their policies and practices with national objectives;
- Lead by example: show good practices in government first;
- Support local projects that move in the direction of greater sustainability, to build local understanding and support; and
- Try new ideas and see what works.

What makes sustainable transportation planning different from past practice is that social and environmental objectives are an integral part of sustainable transportation planning, rather than constraints or the focus of mitigation efforts. European policies on

TABLE 6 European Strategies for Sustainability: Sweden (Stockholm)

Overall Strategies for Sustainability:
- Strategy is "lots of small things" but done in collaboration and put together into an overall strategy
- Access, quality service, safety, good environment, economic development – all objectives for transportation plans
- Transportation providers must meet social and environmental objectives, are evaluated on social and environmental performance
- Collaborative efforts to identify and remove conflicts, pursue areas of agreement
- Strategic planning, performance measures, monitoring, evaluation and feedback to strategic plan
- Environmental goals integrated with planning processes
- Accelerate attainment rather than change direction
- Lead by example – show good practices in govt. first
- Try things out and see what works – e.g., fossil fuel-free community
- Recognize that general public is not so concerned or knowledgeable about global issues, but are concerned about local ones such as too much traffic – build upon local understandings, expand understanding and educate.

Examples of Sustainable Development and Sustainable Transport:
- Emphasis on making transit work – performance goals
- Subsidy reduced but more efficient service
- Customer orientation – market surveys, info systems at stops, remove barriers, etc.
- Quality architecture and landscape design in stations, stops
- New towns at walkable densities, near transit, etc.
- Redevelop centers – recognize cultural and social importance.
- Build and rebuild to reduce negative impacts, e.g., underground roads, traffic calming
- Biodiversity protected through good planning, design, and maintenance
- Remove barriers for animals
- Careful choice and use of road materials; recycled materials used
- Alt. fuels; hybrids for buses and govt. fleets; Zeus project
- Truck improvements being sought – incentives for cleanup
- Rail improvements for freight
- Zero deaths safety plan – grade separation, traffic calming, in-vehicle protection, education

ning for both the long term and the middle term, and backcasting to identify strategies and steps needed to achieve desired results. Another approach with high potential for the United States is the use of performance standards along with monitoring and reporting on progress. Such activity could be coupled, as it is in the countries visited, with fiscal incentives for actions supportive of adopted goals.

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National and International Transport Policy Reform Positions

The European Union issued its Green Paper on transportation in 1995 (*5*), followed by a study of transport pricing by the European Council for Ministers of Transport in 1998 (*6*). The U.S. National Research Council's Transportation Research Board released its own assessment, *Toward a Sustainable Future* (*7*). What each recognized is that certain key externalities, such as safety, air pollution, congestion, noise, and others, represented enormous costs to society. These costs were borne not just by drivers but also by nondrivers, particularly pedestrians and cyclists. The studies recognize that reducing the problems represents challenges to technology and to behavior, both of individuals and governance, that is, collective behavior. What many see as "unsustainable" is the growth in transportation activity—vehicle acquisition and use—that proceeds much more rapidly without internalization of costs or tough regulations to stem some of the worst problems.

The IEA studied how member countries have approached the CO_2 problem (*8*). Four of five European countries studied had begun to strengthen price signals, either through fuel taxes or other forms of taxation that favored cleaner fuels and vehicles and in one way or another discouraged vehicle use. The initiatives in Europe echo the thoughts of the World Bank.

All of the aforementioned studies recognized the importance pricing and of regulations. Although few argue that pricing alone will achieve all of the goals of clean transport, most agree that few private actors (i.e., vehicle and fuel companies, private vehicle users) will change technologies or behavior without both price signals *and* regulation. But it is widely recognized that charging for use of the transport infrastructure and for the externalities imposed on others is politically difficult.

The problems are now recognised in the developing world. Even before the World Bank's *Sustainable Transport* in 1996 broadened the topic to embrace most of the developing world, local and international studies of many metropolises recognized the real costs of both air pollution and congestion on health and human activity; they pointed to the rapidity with which the pollution from transportation often become dominant over that from stationary sources. The World Bank is reviewing its entire urban transport strategy, with a great deal of attention paid to environment (*9*). The Pew Climate Center organized thoughtful reviews by local experts from New Delhi, Shanghai, Capetown, and Santiago (*10*). The IEA is completing a study of advanced bus systems for more than half a dozen of the world's largest cities (*11*). These works point to solutions but also show the challenges to technology, individual behavior, and governance that any solution brings. Thus there is much happening on the urban transport front.

Broader Perspective: Sustainable Transportation

This topic became popular after the Brundtland Commission report of 1987. Not surprisingly, it has been addressed in many of the aforementioned transport studies and dozens more, as can be seen by searching the web for "sustainable transport." Here is an early definition: "Sustainable transport means users and beneficiaries paying their full costs, including those imposed on the future" (*12*). Yet making transport sustainable, however defined, is no simple matter.

The reasons for the difficulties can be seen in the World Bank's description of sustainability with three characteristics:

- Economic and financial sustainability. "To be economically and financially sustainable, transport must be cost-effective and continuously responsive to changing demands."
- Environmental sustainability. "Transport has significant effects on the environment that should be addressed explicitly in the design of programs [and systems in general (our addition)]. Making better use of readily available and cost-effective technology is necessary, but not in itself sufficient. More strategic action is also required in the form of better-directed planning of land use and stricter management of demand, including the use of pollution and congestion charges to correct the relative prices of private and public transport."
- Social sustainability—equity. "Transport Strategies can be designed to provide the poor with better physical access to employment, education, and health services."

The problem with these otherwise lofty ideals is that they lead to conflicts in the sphere we would call "governance sustainability." Few governments can impose regulations and pricing. There are immediate apparent losers: private vehicle owners and transit riders who face higher costs or more inconvenience. There are also apparent losers in the longer term: transport operators and vehicle and fuel manufacturers, all of whom must adjust their business practices.

In IEA countries, unsustainable element of governance appears in many forms:

- Continual changes in the rules of the California Zero Emissions Vehicle rules (for better or worse), as the state of California was recently sued by General Motors Corporation;
- Challenges to European governments over fuel taxation in the fall of 2000 as a falling euro and rising prices of crude oil stimulated truckers to demonstrate for lower road taxes, particularly environmental ones;
- Softening in many key areas of the original plans of European nations to deal with CO_2 in transportation, between the early conceptions of policies in the beginnings of the 1990s to what was on the books by 2000 [IEA 2000 (*11*)]; and
- The abrupt reversal of U.S. President George W. Bush's commitment to restraining carbon emissions.

The same problems plague the developing world in many more critical ways. If one works the first sustainability principal through economically healthy transport, one finds that transport operators, whether public or private, will fight higher costs imposed by the second principal, environmental sustainability. With fares for public transit barely covering costs, few operators want to improve their vehicles or fuels and risk not covering the incremental costs. Also, manufacturers of vehicles for individual personal or freight transport fight regulations on pollution or safety for the same reason: higher first costs threaten sales. In a few IEA countries, these problems are mitigated by differential taxation, such as lowering the acquisition or yearly fees on vehicles that are very low emission or low fuel users. But these countries already charge wealthy users high enough taxes to have room for such adjustments. By contrast, raising diesel taxes in India in 1998 and 1999 was met with widespread protest. Indeed, few developing countries even passed on the full force of crude oil price hikes in 2000. Some major oil producers sell road fuels at less than world market prices. Raising fuel prices to pay for cleaning up the fuel is difficult.

ance these stakeholders and develop strong policies is the key element of governance required for dealing with transport problems. This is shown in Table 1, by Schipper and Marie 1999 (*2*).

The table suggests that there are important groups who would be opposed to fiscal or regulatory measures. Vehicle manufacturers are not opposed to improved fuel economy per se, but because of fears about market acceptance, they are reluctant to commit themselves or their products to significant improvements. The challenge for analysts is to anticipate political opposition, economic difficulties, and other unforeseen problems and incorporate them into sensitivity analysis to gauge the real costs of any development. For developing countries, an additional political issue arises if a policy encourages use of a technology or product that must be imported. Conversely, the fact that some vehicle technologies are poor or old and outmoded in some countries may have more to do with trade and industrial policies than with any problems of local technical competence. India, where older models of British and Japanese cars were produced for many years or even decades, comes to mind immediately, as do the former Soviet bloc countries. Whether such policies are simply protectionist or a result of perception that newer technologies are too expensive, they cannot be put aside easily to make way for progress. Thus many profound positions that must be understood on a local level and met squarely in the political sphere, that is, with political sustainability.

WHAT IS IN THE WAY?

Many factors run deeper than do the problems indicated in the table. Addressing them will take a long-term commitment to fuse transportation issues with progress on other social fronts, that is, improving all four of the elements of transport sustainability.

Serious Inadequacies in Existing Analytical and Advisory Policy-Making Infrastructure

A lack of good data is no excuse for inaction, but it is a good reason to move carefully. Recent experience in many of the worst

TABLE 1 Governance Matrix: Who Cares About Each Policy?

Actor/Option	National and Local Govt.	Vehicle Makers	Consumers, Taxi Drivers, etc.	Stakeholders and Lobbies
Vehicle Fuel Economy	Local: No influence except through procurement. Nat influence through fuel prices, standards, taxes	Hold the technologies	Choose vehicles and how to drive them	Mainly car industry opposing regulations to encourage or mandate. Less opposition to taxation
Fuel Taxation	Set by national or state governments	Mixed position; accept if alternative to regulation, but often defend status quo, especially through their industry associations	Oppose	Opposed in past by many groups
Registration, yearly, or Special Fees	Set by national or local governments	Oppose when aimed at new vehicles	Oppose	Opposed by principal transport industries (e.g., airlines opposed landing fees, etc.)
Km Pricing (including congestion pricing, etc.)	Local and national favor for different reasons	Few have thought through what significantly lower utilization/year would mean for sales and planning	Would oppose unless congestion benefits clear	Probably opposed, particularly by truckers and other transport professionals
Cleaner Fuels	Set standards	Usually accept because of beneficial impacts on vehicles	Mixed, depending on costs	Often opposed by national oil companies and refiners, or transporters who have to pay the extra costs
Alternative Fuels: Development, Pricing	R&D, testing, pricing, introduction into market	Mixed reaction Could favor	Suspicious unless price differential	Lobbies for fuels develop quickly
Transit Development	Crucial for planning, financing, running (?)	Some taking proactive stand (Volvo)	Urban interested; suburban not	All sides of issue
Land Use Planning	Local Gov. implements, but can be based on national laws	No view	Take both sides	Usually real-estate interests, property owners organize to oppose

SOURCE: Schipper and Lilliu-Marie, 1999.

Thus to a large degree, the characteristics of technology performance, behavior, and lifestyles; and the capacity of national or local policies and corporate or local, nongovernmental initiatives to affect transportation are simply too poorly known to draw lessons, spot winning technologies, correct undesirable trends, or reinforce successful initiatives. For policy makers and donor agencies, this means it is almost impossible to design optimal interventions or to measure the added value of an intervention. Trends need to build up for a decade or longer before they emerge in a well-understood way, by which time it is often too late to change policies or change technologies except at a very large cost.

Political Difficulties: Divided Markets and Divided Responsibilities

One of the paramount problems of governance in transportation is that of divided responsibilities. Consider these examples of sensitive local situations where either markets (i.e., economic competition) or responsibilities (political competition) are divided:

- The role of paratransit is a sensitive issue in many large cities, because in the transport market, paratransit is both a competitor of and a complement to organized public transit. In most Third World cities, informal transportation (or paratransit) coexists with formally organized municipal buses, trams, and metros in a relationship that may not be totally sanctioned by the authorities. In Mexico City, about 30,000 *colectivos* (minibuses and vans, akin to small busses in the United States and similar to those around the world) have managed to garner about 50% of all trips in that region, mostly at the cost of regular bus and metro riders, but probably absorbing some car trips as well. Politically, the colectivos are tolerated, yet represent a chaotic, uninsured, and sometimes unsafe mode of transport that nevertheless delivers a much-desired service. Unquestionably, the drivers are a strong political force. In Brazil, the equivalent modes have been brought into the system in some cities and tolerated in other cities, yet officially hated in most. Given this tension, little effort has been made to clean up the vehicles or organize the routes to fit with bus and metro systems. Indeed, the appropriate vehicles are virtually unavailable as new vehicles in Mexico City today, making the existing aging fleet old and polluting (The colectivos consume more gasoline than the buses from the two public companies consume diesel). Any transport solution must fit this kind of local circumstance squarely into the picture. But currently, the antagonism among all parties makes exploiting synergies impossible.
- Fierce competition between collective and individual modes has arisen in many cities, always as a function of peculiar local conditions. In Delhi and other Indian cities, the most important mode of motorized transport is the two-wheeled scooter, most of which have dirty two-stroke engines. They compete directly with buses for much of the mobile middle class. Because they are so numerous, they are a significant source of air pollution and congestion; in fact, they consume as much as 66% of all gasoline in metropolitan areas. Although most manufacturers are switching to clean, four-stroke engines (and even CNG for the three-wheeled taxis), these vehicles will remain a huge source of air pollution for many years. If bus fares are raised to permit acquisition of modern, comfortable vehicles with improved motors and clean fuel, one result could be further erosion of the bus market and a worsening of both air pollution and traffic. Yet if bus fares do not rise, bus operators (public, contract, and private) will stick with old, polluting vehicles based on ancient designs, putting bus bodies on truck chassis.
- In some important regions, political parties have divided authorities. In São Paulo and Mexico City alike, the mayor is of a different party than is the national or state government. This situation tends to impede progress. Divided responsibilities separate those pushing technologies from those who use them. Indeed, new technology may be the least important component of the solution unless its acquisition and use is carefully adapted to these kinds of local conditions. In Brazil, for example, there are enormous potential gains to be made by improving bus technologies. But the owners of buses are rarely the operators. Whether owned by contractors to large cities (as in São Paulo) or by speculators, buses are resold after only a few years in service to the original purchaser. Most make their ways from larger to smaller cities. Hence, few original purchasers are interested in expensive buses that they may not be able to resell. In El Salvador, virtually all buses were purchased used, primarily from the United States. Also, in both countries, small private operators dominate the bus business, few of whom can afford to buy more expensive, modern buses. Although technologies to both improve fuel economy and drastically cut emissions in buses in both countries seem attractive, the present organization of the bus market presents a formidable barrier, even in the cities of Brazil with the most advanced systems, such as Curitiba.

GOOD NEWS: POLICIES AND TECHNOLOGIES ARE BEING DEVELOPED

Lest this review appear unduly pessimistic, it is aimed only at being realistic. Recognizing barriers and failures is as important as crowning successes, because lessons learned all around help guide future actions. Indeed, actions are being taking in key areas. Here is what has been under way: removing lead from gasoline; lowering the sulfur content of fuels; raising vehicle pollution controls; imposing some controls in traffic; and working through the governance process to bring transport operators as well as private citizens and NGOs, fuel companies, and vehicle producers into a dialogue. In parallel is a larger array of smaller projects and collaborative initiatives among stakeholders emanating from multilateral agencies, private donors, NGOs, and the private sector, and all targeting transport's environmental and economic externalities. This array includes the World Business Council for Sustainable Development Industry Collaboration on Transportation or the World Bank's "Clean Air Initiative" with local governments in Latin America and Asia.

Compared to the scale of the problem, these moves are very limited. Some even backfired. But they at least indicate that the public, politicians, the policy-making system, and even major private-sector players are beginning at last to engage seriously with the transport dilemma and starting to look for answers. This upward trend in the demand for action emanating from the public and the public sector can only accelerate in the future. Here are some examples:

- Mexico City's "hoy no circulan" was a policy that dictated that a car could not be driven one day per week, with the designated day depending on the last number of the license plate. Newer cars with modern clean exhaust systems were exempt. The World Bank (*22*) showed that the policy stimulated a significant uptake, by those who could afford them, of used cars with license plates covering the fifth day. This led to more driving and more fuel use, not less, since more cars were available.
- Low-sulfur diesel in Europe and the United States is a trend. Pioneered in Sweden ("city diesel"), very low-sulfur diesel has appeared increasingly in bus fleets in Paris, London, and more recently in U.S.

less motion, but not necessarily less access to people, goods, and services. In developing countries, this barrier must mean more access to the same ends, without the endless chase to be like Americans, Europeans, or the Japanese. What is working so hard against developed countries is the generations of habits built up around individual motorized transport; what is pressing hard against developing countries is the huge and rapidly growing scale of the challenge, exacerbated by swollen urban population and inadequate infrastructure to deal even with last year's problems. But developed countries are wealthy and innovative, so that deep cuts will work their way slowly but surely through the problem. Developing countries are growing and changing so rapidly that even modest cuts in some forms of emissions rapidly become the norm as vehicles are replaced, and citizens can grow into new patterns of mobility and access before they get mired in the old ones.

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dramatic changes in small towns in Texas. These results provide some direction for both TxDOT and local communities regarding what they can do to minimize the negative impacts of the relief route and maximize the positive impacts.

METHODOLOGY

The first step in the case study methodology was the selection of 10 case studies from an initial list of 23 communities with relief routes identified in Phase 2 of the project and the selection of 4 additional case studies from the list of communities without relief routes. Data collection for the case studies included compilation of information available through chambers of commerce and other sources, phone and on-site interviews with selected members of the community, and on-site observations of the community. Key methodological issues included the criteria used to select the case studies, the strategies used to identify appropriate community members for interviews, and the techniques used to analyze the information collected.

Case Study Selection

A variety of criteria were used to select the 10 case studies from the entire set of cities with relief routes. The most basic criterion to be satisfied was representative geographic coverage. The geographic diversity of Texas is apparent not only in physical and climatic features but also in cultural identity, economic conditions, and population distribution. All of these factors may help to shape the impact of the relief route on the local community. Five regions within the state were defined and at least one community was selected to represent each region (Figure 1).

Communities were also selected based on several other geographic characteristics, including size of the community, ex-urban versus rural status, and geographic isolation. Communities were selected to provide a range of sizes up to 50,000 residents, with most communities from 5,000 to 10,000 residents (Table 1). As it turns out, few cities with relief routes in Texas fall into the 10,000- to 40,000-population range. The distinction between ex-urban and rural communities was thought to have a potentially significant influence on the impacts of the relief route and so was also included as a criterion. Geographic isolation adds another potentially important dimension beyond the size of the community.

The age of the relief route played a critical role in case study selection. It was important to find relief routes old enough for impacts to have occurred, but not so old that impacts could not be studied. In addition, the newer relief routes were almost always built as limited-access facilities. Because most of the additional relief routes that TxDOT now proposes for Texas communities will be built as limited-access facilities, these newer examples were deemed to be more appropriate as case studies. However, TxDOT has established a new policy that the new relief routes will not have frontage roads, unlike those of existing relief routes, which were almost always constructed with frontage roads. Generally, the relief routes in the selected case studies were built after 1980, but various considerations have led to the selection of two older relief routes. Two sets of case studies are located along the same highway and thus share the same traffic stream, thereby controlling for one potentially important variable.

The four nonrelief route case studies were included to provide a base line for the relief route case studies. An analysis of the changes

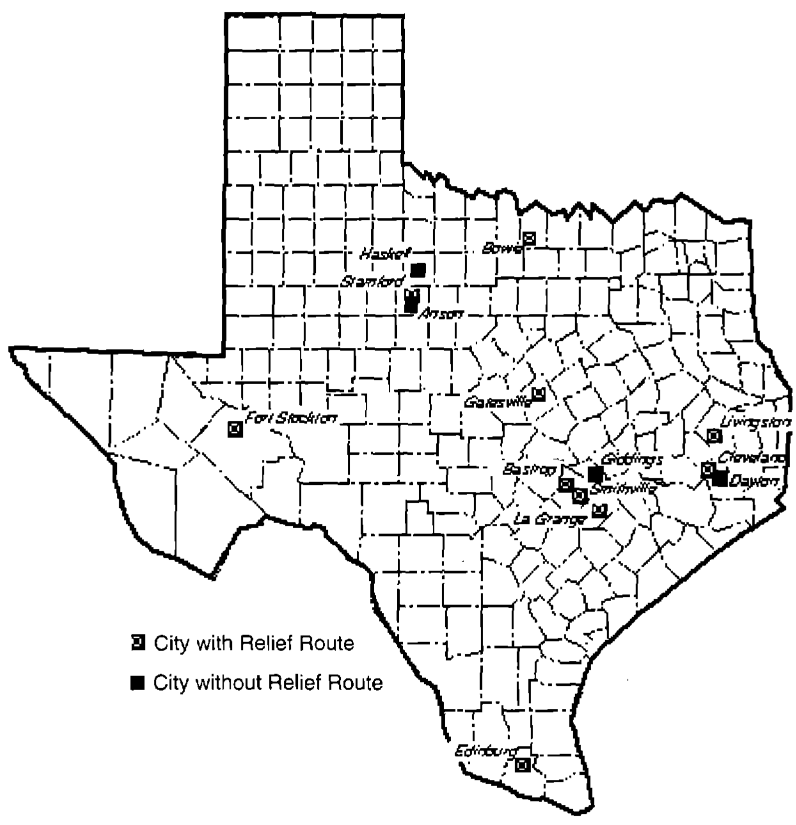

FIGURE 1 Texas case-study communities.

and major employers. Data on local sales and establishments came from the U.S. Census of Retail Trade, and population data came from the U.S. Census of Population and Housing.

Interviews were examined using a common framework across case studies. First, residents' initial concerns and opinions—the gut reaction townspeople had to the relief route when it was proposed and designed—were examined. Second, the anticipated impacts of the relief route before its construction were examined. Third, the realized impacts of the relief route as perceived by the interviewees were analyzed. This analysis became challenging by the fact that interviewees frequently gave conflicting information or cited conflicting causes for the current condition of their communities, depending on their perspectives and perceptions. Fourth, using information gleaned from site interviews plus observations made during the site visits, the new development that had occurred following the construction of the relief route was documented and the factors explaining that development were identified. Finally, interviewees provided insight into the communities' current feelings about the relief route.

This combination of data sources formed the basis for objective accounts of the current conditions in the communities and the factors leading to those conditions. In addition to the analysis completed for each case study, a comprehensive analysis was conducted to identify patterns across case studies. This comprehensive analysis examined trends not related to relief routes, which may mask the impacts of a relief route; it also identified several geographic factors, characteristics of the relief route, and local actions that determine and influence the impacts of a relief route.

SUMMARY OF CASE STUDY ANALYSIS

The case study methodology does not provide statistically significant results, but it does enable a more in-depth and exploratory look at what happens to a community after the construction of a relief route and why. Each of the stories developed for the case studies is unique in important ways. Yet together they paint a relatively consistent picture of the impacts of relief routes on small communities and of some of the key factors that determine those impacts [these stories are reported in Handy et al. (*4*)]. This section describes the common themes as well as the important exceptions that emerged from the comprehensive analysis of the case studies. The impacts and key factors explaining those impacts in each case study are summarized in Table 2.

TABLE 2 Summary of Changes and Key Factors

	Changes			Key Factors*									
Case Study	Changes in Downtown Businesses	Development on Relief Route	Net Change in Highway-Related Businesses										Unique Factor
Bastrop	change	lots	increase	+			+						uncontrolled access
Bowie	change	slow	decline	+	–			–		–	+	–	
Cleveland	decline	slow	decline	+	–			–					
Edinburg	change	slow	no change		–	–		–			+		
Fort Stockton	decline	slow	increase			+	–						
Gatesville	change	slow	no change							–		–	prisons
La Grange	increase	slow	increase				+			–	+		Main Street Program
Livingston	change	lots	increase	+		+	+	–		+			lake
Smithville	change	slow	decline	+	–			–	–			–	
Stamford	decline	slow	decline	–	–		–		–				dry country
Anson	decline	n/a	decline	–	–								
Dayton	decline	n/a	decline	–	–								
Giddings	decline	n/a	increase	+			+						
Haskell	decline	n/a	decline	–	–		–						

* – = negative impact on community, + = positive impact on community.

gram is similar to the national Main Street Program, administered by the National Trust for Historic Preservation.) But otherwise this success is hard to explain. In all the case studies, it seems likely that such changes would have occurred even without the construction of the relief route, although the relief route may have magnified them. All four nonrelief-route communities experienced a decline in downtown businesses.

Development Along the Relief Route

If the greatest fear is the decline of downtown, then the greatest hope of communities facing the construction of a relief route is that it will open up a new corridor of development and attract new businesses to the community. In all 10 case studies, some development has occurred along the relief route. In eight of those studies, however, the amount of development is considered limited, at least regarding the hopes and expectations of the community. Most new development is concentrated at the interchanges of the relief route rather than along the frontage roads, even where two-way frontage roads and the necessary utilities have been provided. In several cases, development is concentrated on the old route near the interchange of the old route with the relief route. In most cases, the development mainly consists of businesses new to the community rather than existing businesses that have relocated to the relief route. Two factors seem to explain the limited number of relocations in these communities. First, most businesses in these communities, before the opening of the relief route, were locally owned and lacked sufficient resources to finance a relocation. Second, the owners of many of these businesses were approaching retirement age and lacked sufficient interest in relocating, often preferring to simply close down and retire in the face of a decline in business. Many of the new businesses locating along the relief route were national or regional chains or locally owned franchises of national chains. Although residents did not express concern about this trend, it may have important implications for the community. Those businesses are often less inclined to purchase their supplies locally and are more likely to spend their profits elsewhere. One could also argue that communities begin to lose their unique local character as chains move in. In each of those eight communities, some development has occurred along the relief route.

Two of the case studies, Bastrop and Livingston, have seen a significant amount of development along the relief route, at least compared with the other case studies. The relief route in Bastrop is the oldest of those studied and is the only uncontrolled access facility. These characteristics help to explain why so much development has occurred along this route. In addition, the proximity of Bastrop to Austin has contributed to an explosion in the local population and the services needed to support the new residents. The development along the Bastrop facility has become so intense that the TxDOT is in the process of planning an upgrade of the relief route to a controlled-access facility. In Livingston, the heavy stream of travelers from Houston to Lake Livingston who use the relief route helps to explain the extent of development there. Until recently, most of the development was along the southern portion of the relief route, that is, the stretch of the relief route used by lake-bound travelers. More recently, businesses catering to local residents have opened along the northern portions of the relief route.

Net Change in Highway-Related Businesses

The owners of highway-related businesses, including service stations, motels, and restaurants, express the greatest concerns before the construction of a relief route, understandably so. They depend on pass-by traffic for much of their business and may fall into the red with even a small decline in traffic. The available evidence in the case studies suggests that at least four of the case studies experienced a net decline in highway-related businesses after the construction of a relief route. In places like Bowie, Cleveland, Smithville, and Stamford, empty gas stations and motels line the old route and have not been entirely replaced by new businesses on the relief route. The dramatic decline in traffic on the old route in these communities, even after a period of time (see Table 3), provides an obvious explanation for the decline in these businesses. However, highway-oriented businesses have also been affected by dramatic changes within these industries that also help to explain this net decline. Note that each of the nonrelief route-communities experienced similar declines in traditional highway-oriented businesses. In addition, the change in sales might not match the change in numbers of establishments, if the new businesses are doing bigger volumes than were the old ones. Edinburg and Gatesville have seen little change in highway-related businesses, mostly because these businesses were not a significant part of the economy before the relief route. Even with the relief route, traffic volumes remain low. Bastrop, Fort Stockton, and La Grange seem to have experienced a net increase in highway-related businesses for different reasons: Bastrop because of the uncontrolled-access facility, the age of the facility, and population growth in the area; Fort Stockton because of its geographic location that makes it a natural stopping point; and La Grange because of its success in maintaining existing businesses while still attracting some new development along the relief route.

Key Factors

The case studies also help to shed light on the key factors that have shaped the changes within the community and influenced the nature and extent of the relief route impacts on the community. Although residents, business owners, and civic leaders all point to the relief route as causing changes in the community, mostly negative but some positive, they also identify other important factors unrelated to the relief route that may be to blame. Most interviewees view the relief route as an exacerbating factor rather than a primary cause of the current state of the community. Two categories of factors emerged from the case studies: structural factors related to trends in the national economy and demographic patterns; and local factors related to the geography of the community, the characteristics of the facility, and the policies of the local government.

Structural Factors

None of these communities is insulated from larger trends in the national economy and in demographic patterns. Three trends seem to have had a notable effect on the case study communities: the decline of rural populations and growth of metropolitan areas, increases in the scale of stores and shopping centers in the retail industry, and consolidation in distribution channels for gasoline. These trends may explain some of the impacts commonly attributed to the relief route.

For most of the 20th century, rural populations declined as a proportion of the total U.S. population. At the same time, metropolitan areas were growing, largely at the fringes. Innovations in farming technologies have led to larger farms that employ fewer people. As farm populations have declined, so have the economies of the small- and medium-size towns that supplied their needs. This trend has affected towns like Fort Stockton, Smithville, and Stamford and its neighbors are relatively low. Similarly, US-277 does not carry enough traffic through Stamford to justify the construction of service stations, convenience stores, or restaurants. Edinburg also suffers from a low volume of traffic through town.

Facility Characteristics The characteristics of the facility itself may determine its impacts on the community. The most critical decision the DOT makes is the alignment of the new facility. The most common complaint from residents and civic leaders in the case study communities was the choice of alignment. There are two primary ways in which alignment affects the community: the location of intersections with other highways and the type of land adjacent to the relief route. Livingston provides an example of both. US-59 travels west of downtown Livingston and intersects with US-190, 1 mi due west of downtown. Given the current alignment, travelers from Houston to Lake Livingston bypass downtown Livingston. Some local business leaders argued that an eastern alignment would have forced lake-bound traffic through downtown, thus helping to maintain the viability of existing businesses but doing nothing to alleviate local congestion. In Bowie, Cleveland, and Livingston, the alignment passes through land that is less than optimal for development. In Smithville, the alignment is mostly too far from the town to make stops there likely for through travelers. In Edinburg, the relief route was located on the opposite side of the city from the direction of greatest growth. In many cases, the relief route passes through areas where landowners are not interested in developing or selling, a problem discussed later. Of course, in the communities where the alignment was raised as an issue, it is not always clear what other alignment would have been better or even feasible.

Access is another critical issue in determining the potential impact of a relief route. Access can be broken into three components: frontage roads, the number and location of interchanges, and the visibility of interchanges. When discussing access to the facility, interviewees frequently complained about one-way access roads, which they felt would inhibit development because customers would not put up with the hassles of dealing with such roads. However, in most of the case studies, TxDOT in fact provided two-way frontage roads, but these communities still saw little development away from interchanges. The number of interchanges and their location are also critical. Many highway-related businesses rely on the local market as well as through traffic. If the interchange is too far from the center of town, businesses at the interchange might not be able to draw enough local business to survive. At the same time, existing businesses in town may fail due to the loss of through traffic. With only two interchanges relatively far from the center of town, Smithville suffers this fate. The more universal problem seems to be the visibility of the town from the relief route as determined by both the location and design of interchanges and by signage. Stamford has extremely poor visibility, for example; we accidentally passed Stamford on our site visit and did not realize our mistake for several miles. This problem can affect both highway-related businesses and tourist businesses often found downtown.

One more facility-related factor merits mention. In several cases, notably Cleveland and Edinburg, the length of time between the decision to build a relief route and the construction of the route was long enough to create a pervasive sense of uncertainty that may have inhibited development. In the case of Cleveland, the uncertainty was due to lengthy delays in construction. Citizens were not kept apprised of new developments in the highway project and many forgot it was being built or were not sure when the highway would be constructed. In the case of Edinburg, uncertainty in the alignment kept some property owners from developing their land. Uncertainty not only may stifle development, it may also deter the local community from taking steps to mitigate the impacts of the relief route.

Local Actions The actions of local governments also help to determine the impacts of the relief route. Most obviously, the decision to annex the land adjacent to the relief route and provide utilities and other city services seems to be a necessary but not sufficient condition for new development. The decision not to provide utilities, or delays in providing utilities, can inhibit new development along the relief route, as was the case in Bowie, Gatesville, and La Grange. It was not clear in these cases, however, whether the delay in providing utilities was a conscious effort of local government officials to discourage development. Once local governments have annexed the land along the relief route, they can also zone this land for development. In nine of the case studies, zoning was not cited as a factor in either encouraging or discouraging development, however. Edinburg, where much of the land along the relief route remained zoned for agricultural uses, was the one exception.

City programs to promote development can help to mitigate the impacts of the relief route and other trends affecting the community. Bowie, Gatesville, and La Grange are a part of the Texas Main Street Program that helps communities to preserve and enhance their historic downtown areas. The program in Bowie has helped to build a tourism economy that has at least partially offset the decline in highway-related businesses that occurred after the opening of the relief route. The program in La Grange has contributed to the continued presence of many traditional businesses in the downtown area that still cater to local residents. In contrast, city officials in Edinburg worked to encourage development along the relief route through public–private partnerships. This effort has had some limited success but has also created considerable controversy within the community.

In a number of communities, the owners of land along the relief route were apparently uninterested in developing their land. In places like Gatesville, the willingness of particular landowners to subdivide and sell their land explains much of the development along the relief route. This factor also proved significant in Bowie and Stamford. If this is the case, there is not much that the city can do to encourage development. The choice of alignment may determine whether this factor will surface, however.

CONCLUSIONS

The case studies cannot be used to predict what will happen in communities where relief routes are proposed. The larger national trends affecting the communities described here may decline in importance while others grow. Unique characteristics may make a particular community an exception to the patterns identified here. However, the case studies do provide an indication of what factors might come into play and what kinds of impacts a small community might experience as a result of the construction of a relief route. Although the case studies suggest that geographic factors are strong predictors of how a community will change as a result of the relief route, they also provide some direction for both DOTs and local communities regarding what they can do to minimize the negative impacts of the relief route and maximize the positive impacts. Strategies for DOTs to consider pertain to the design of the relief route, including alignment, visibility, and access. Strategies for local communities to consider include traditional land use controls such as zoning and utility provision, as well as more innovative economic development programs.

Automobile Ownership, Households Without Automobiles, and Urban Traffic Parameters

Are They Related?

Matthew Karlaftis and John Golias

Most research to date on automobile ownership has concentrated on establishing links between various socioeconomic factors and automobile ownership, without much regard to urban traffic parameters that may affect ownership rates. To address the issue of the effect of traffic parameters on ownership rates, the study takes a twofold approach. First, it investigates whether traffic characteristics and network efficiency parameters influence automobile ownership. Second, it investigates whether not having an automobile (autolessness) is also affected, and to what degree, by these parameters. The results clearly suggest that the variables affecting automobile ownership and autolessness are not the same. It further suggests that traffic network and efficiency parameters do not, on one hand, affect autolessness, but they do, on the other hand, affect the number of automobiles owned by a household. What this seems to imply is that a household's decision to purchase the first automobile is primarily based on socioeconomic factors, whereas the decision to purchase a second automobile (or more) is largely based on traffic network, efficiency, and transit level-of-service parameters.

The private automobile is an indispensable part of all aspects of modern life; as such, the trends in modern transportation research that show a large interest in the general area of automobile demand and related topics such as automobile ownership, vehicle purchase models, vehicle holdings and usage models, autoless households, and others are not surprising. Generally, modeling research related to automobile demand has revolved around three important areas: automobile ownership, vehicle purchasing, and vehicle holding and usage. In the transport literature the term "automobile ownership" generally refers to the decision of how many automobiles to own (fleet size). A large number of academic studies have dealt with this topic, mainly as a result of its close link with aggregate automobile demand (*1–9*). Further, a number of recent works [thoroughly reviewed in Gardenhire (*10*)] have focused on the issue of autolessness, which attempts to model the factors that determine whether a household will be with or without a vehicle (modeled as a binary choice model).

Despite the significant attention given to automobile ownership models in the scientific literature, most of these are geared toward establishing links between ownership and socioeconomic characteristics, with a particular interest in the effects of income on ownership. But as Tam and Lam (*11*) report, there is frequently a significant discrepancy between estimated and actual car ownership that could be attributed, in large part, to the noninclusion of traffic network and urban development parameters in the models. The lack of inclusion of traffic parameters may result, at least in part, from the difficulty in collecting relevant data, but it would nevertheless be of significant interest for transportation planners. Such models, containing network efficiency parameters besides socioeconomic factors, would be both theoretically superior and statistically more efficient and would allow for detailed policy analyses to be performed on issues such as the impact of local changes in transit and highway infrastructure, impacts of modal quality of service, provision of additional parking facilities, and others.

This paper examines two important issues. First, it investigates whether traffic characteristics and network efficiency parameters influence auto ownership. Second, it investigates whether autolessness is also affected, and to what degree, by these parameters. Differences in the parameters that affect these two characteristics may explain household decisions to purchase and use more than one automobile. To achieve these goals, this paper estimates two analytical models that connect automobile ownership and autolessness with both socioeconomic and network efficiency parameters. To develop these models, data from a detailed local travel survey at individual traveler level from Athens, Greece, are used. The remainder of this paper is organized as follows: The next section reviews many previous studies on both aggregate and disaggregate automobile ownership estimation. The third section discusses the data used and the fourth section reviews the methodological approach used in this paper. The fifth section presents the results of the estimation methodology, and the sixth section summarizes the findings of this paper.

BACKGROUND

As previously discussed, automobile ownership has received considerable attention in the travel demand analysis literature because of its important role in many transportation and land use considerations. It has been well established in the literature that automobile ownership affects, for example, trip frequency, mode choice, propensity to chain activities during a trip, etc. To quantitatively investigate these questions, the literature on automobile ownership has taken either an aggregate or a disaggregate modeling approach. Both approaches have a number of associated advantages and disadvantages and can respond to different types of questions.

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Summary of Findings and Contribution of This Study

What becomes quite apparent from this brief review of previous work is that the investigation of automobile ownership has mainly revolved around estimating the effects of income on ownership levels. Further, despite the vast literature on automobile ownership, there is a marked absence of work relating ownership to traffic network and urban development parameters. But as Huey and Everett (*31*), Newman and Kenworthy (*32*), and Noland (*33*) have shown, these parameters are very important in explaining automobile and transit use. For example, Noland (*33*) suggests that the lack of frequent transit services has often been cited as a reason for the preference travelers have for private automobiles, whereas Huey and Everett (*31*) suggest that the benefits of using an automobile (convenience, privacy) are very immediate to the user whereas disadvantages (maintenance costs, pollution) are delayed in time, thus encouraging consumers to buy and use an automobile rather than use transit.

This paper extends previous research both in terms of the methodology and the explanatory variables used. First, instead of using the ordered or the unordered mechanism for modeling automobile ownership, this paper recognizes the explicitly count nature of the dependent variable. Also, it estimates appropriate models for such data that make few assumptions about the underlying structure of the estimated models. Second, besides a wide variety of socioeconomic variables, this paper uses a number of traffic efficiency parameters to investigate their effects on car ownership levels.

DATA

Athens, Greece, Urban Transport System

The urban area of Athens, the capital of Greece, has an area of 1470 km^2 and a population of approximately 3.7 million people. During the last decade the population in the greater Athens area has increased by about 10% while at the same time car ownership has increased considerably, approaching 250 private automobiles per 1,000 inhabitants in 1996 (car ownership in 1983 was 172 automobiles per 1,000 inhabitants). The result has been an increase in travel time by 26% in the last 12 years which, along with the insufficient urban road network in the central areas, has led to a deterioration of traffic conditions in the capital.

For the Athens Metropolitan area, there are 6.3 million single mode daily trips, a 26% increase between 1984 and 1996. Further, there are 1.72 daily trips per person (1.54 journeys/person), while 55% of the population makes at least one trip per day, with business and education trips (45% and 15% of total daily travel, respectively) having the highest share. Athens is served by a mass transit system of 1,840 buses, 1,500 of which are in operation daily, 356 trolley buses, 290 of which are in operation daily, and 3 metro lines with 269 cars. The bus system is made up of 41 trunk lines, 116 central lines, 9 intermunicipal lines, 98 local-feeder lines, 8 express lines, and 6 school lines, with a total annual ridership of 403 million passengers. This ridership is complemented by an annual 90 million in ridership for the trolley buses and 92 million passengers for metro. Transit providers must serve a system that has experienced a 3.5% annual increase in traffic for the last 10 years and that has high congestion at 22% of the signalized intersection approaches in the center of the city. Obviously, the provision of high-level transit services in such a congested network is very difficult.

Data Collection

The data needed to estimate both automobile ownership and autolessness, as well as to estimate the impact of the potential change of various network efficiency parameters on automobile ownership, can best come from a dedicated and detailed traveler survey. The survey developed included a large number of inquiries, including questions on mode choice, travel time, travel cost, trip purpose, socioeconomic characteristics, travel time and cost for alternative modes, and trip chain behavior. The surveys were completed in two locations: on board, with face-to-face interviews for Metro and transit riders, with roadside interviews for automobile users. It should be mentioned that the main goal of this survey was to assess both the underlying characteristics of automobile ownership and the potential changes in ownership from a change in commuting parameters. To select the most representative sample of bus and Metro riders and automobile users, a multistage stratified sampling process was followed.

The strata of the survey were the three main modes considered (bus, Metro, automobile) and the six different types of lines within the bus network (trunk lines, central lines, intermunicipal lines, local-feeder lines, express lines, and special lines). From each stratum, a random sample of lines was selected, the size of which was proportional to the ridership of the stratum, with the probability of selecting each line proportional to its ridership (proportional to size sampling). Finally, weighted random sampling (using age and gender as the weights) was used to select the interviewed individuals.

To avoid the problem of nonresponse from automobile users, help from the police was requested. A police officer was present during the entire duration of the roadside interviews to stop drivers and ensure that they would respond to the questionnaire. For the onboard surveys, the response rate was very high (more than 90%), since an explicit effort was made to interview passengers who had just boarded the bus and had adequate time before getting off the bus. A total of 5,028 complete questionnaires were collected (the questionnaires and the database are available from the authors on request). Further, it should be noted that after the questionnaires were completed, much work went into determining distances, travel times, and residence location for each respondent. The independent variables to be used in the estimation process include most socioeconomic variables encountered in similar studies (income, education, type of work, gender, age, number of adults in the household, job description for head of household, residence location), trip characteristics (travel time, travel cost, value-of-time for each traveler), and network efficiency characteristics (number of mode transfers during the trip, number of alternate modes used, speed of travel and travel distance).

Table 1 describes the modal distribution of the sample collected, while Table 2 describes modal use and gender. Of note is that there is a higher percentage of bus users among the female population, whereas automobile users are predominantly male; both findings agree with previous work on modal use in the Athens region. Table 3 describes the number of vehicles owned by households, stratified by the mode used by the respondent. This table reveals that almost one-fourth (24.5%) of the sample belongs to autoless households, with about 50% belonging to a one-automobile household. The table also

TABLE 1 Sample Distribution by Mode of Travel

		Mode				
	Total	Bus	Bus/Metro	Metro	Metro/Auto	Auto
Frequency	5028	1278	1518	184	1048	1000
Percent	100	25.4	30.2	3.7	20.8	19.9

$$E[y] = e^{\beta' x} e^{\sigma^2}$$

$$V[y] = e^{\beta' x} e^{\sigma^2} + e^{\beta' x} \sigma \left(e^{2\sigma^2} - e^{\sigma^2}\right) \tag{7}$$

This model induces overdispersion as $V[y] = E[y]\{1 + E[y]e^{\sigma^2} - 1\}$ if $\sigma^2 = 0$, $E[y]$ reduces to the Poisson mean, and $V[y] = E[y]$.

Autolessness Model

Unlike the data available for automobile ownership models, that is, number of automobiles in a household (count data), the data for autolessness models are binary, taking the value of 0 for households with no automobiles (autoless) and 1 for households with automobiles (regardless of the number of automobiles in the household). Such data are extensively modeled using the very popular binary probit and logit specifications. To depict the relationship between autoless households and independent explanatory variables, the familiar logistic regression formulation is used:

$$\log\left(\frac{P_i}{1 - P_i}\right) = \alpha + \boldsymbol{\beta}' \mathbf{x}_i \tag{8}$$

where $\boldsymbol{\beta}$ is a vector of parameters to be estimated and $\mathbf{x}_i$ is a vector of exogenous variables for individual i. In this form of the logistic regression model, the dependent variable is the logarithm of the probability that a particular choice i [autoless (0) or not (1)] will be made over the probability that this choice will not be made.

EMPIRICAL RESULTS

The final model specification for both the automobile ownership and the autolessness models is presented in Table 5. It should be noted that more than 5,000 questionnaires (5,028) were used in this analysis. In the initial model estimation, the full set of available independent variables was used; this included a number of variables that do not appear in the final specification. The independent variables presented in Table 5 make up the final model that was developed using both previous research, presented in the second section of this paper, and Akaike's information criterion. It should be noted that a series of market segmentation tests was used to determine whether separate models should be estimated for each mode; the tests suggested that such separate estimation is not needed.

It is interesting to note that regarding most of the socioeconomic independent variables, the results confirm prior research and a priori economic arguments. The results clearly suggest that socioeconomic factors such as income, age, and number of adults in the household are clearly, at least statistically, related to automobile ownership and autolessness. They further suggest that increases in these factors cause increases in automobile ownership and reduce the probability of a household's being without a car. Interestingly, gender, a variable with varying directional findings in previous work, had very low t-statistics in both models. Consequently, it can be inferred that gender is not, at least directly, a determinant of automobile ownership in the context of this work. Urban residence appears to be a deterrent of higher automobile ownership, since urban area residents have, on average, 0.89 automobiles fewer than do residents in nonurban locations (suburbs). One final socioeconomic finding of importance is that of the value-of-time variable. This variable is statistically significant in both the automobile ownership and the autolessness models. It is a finding of particular interest, since the value-of-time variable appears to be significant despite the presence of an explicit income variable. The value-of-time variable used in this work is a derived value, not an observed value, since its values were obtained from an explicit mode choice analysis. This situation seems to indicate that this variable acts as a proxy for travel time or travel cost, or both, or even for another not indirectly captured by income. As expected, the higher the value individuals place on their time, the more automobiles they own and the more likely they are not to belong to an autoless household. This is of course true under the common assumption that automobiles have lower travel times than do other modes of transportation.

These findings, relating socioeconomic factors to both automobile ownership rates and autoless households generally confirm previous research and appear to suggest that the two dependent variables examined abide by the same underlying economic principles in Athens as they do in most other areas of the world where they have been studied. But an interesting scientific question as well as policy question can be raised: do the independent variables included in the automobile ownership specifications exhaust the two phenomena under study, or could other variables influence them as well? If other variables, unaccounted for in existing literature, affect automobile ownership, then both policy-related opportunities may have been missed and coefficient estimates for the examined socioeconomic factors may have been biased. Thus, this study includes variables such as speed of travel, number of transfers, and others that act as

TABLE 5 Estimation Results

	Dependent Variable	
	Number of Cars in Household[a]	Carless Household?[b]
Independent Variable	Coefficient estimates (t-ratios)	
Intercept	-1.71	0.0042
	(-5.51)	(0.34)
Income	0.037	0.447
	(2.93)	(13.71)
Age	0.11	0.024
	(1.17)	(1.77)
Number of household members over 18	0.192	0.311
	(14.01)	(13.27)
Urban residence	-0.885	-0.81
	(-3.17)	(-1.97)
Value of time	0.037	0.040
	(3.11)	(5.754)
Speed (bus)	-0.017	0.027
	(-2.17)	(0.43)
Speed (auto)	1.371	0.279
	(3.37)	(1.47)
Number of transfers (bus)	0.27	0.10
	(2.73)	(1.31)
Travel distance (auto)	0.059	0.028
	(2.01)	(2.01)
Time searching for parking (auto)	-0.091	-0.009
	(-6.01)	(-1.17)
Summary Statistics		
Number of Observations	5028	5028
Rho-squared	0.43	0.31

[a] Poisson model with normal heterogeneity.
[b] Binary logit model.

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in constant dollars (i.e., disregarding inflation), median household income is quite steady over time. However, other analyses have suggested that those in the top 25% of household income are gaining in earning power, whereas those in the middle 50% are declining somewhat, and those in the lowest 25% are holding steady (2).

Generally, the analyses compared the impacts of the plan with the baseline impacts—those that would occur in the plan horizon year of 2025 if the plan were not enacted. The analyses represented the effects of the plan as a whole, not of individual projects within it, though wherever possible, results were aggregated from small-area data (e.g., model results).

DISTRIBUTION OF OVERALL PLAN BENEFITS AND COSTS

SCAG conducted a number of analyses designed to assess the equity of the 2001 RTP for minority and low-income populations in the region. Initial analysis focused on the distribution of overall plan benefits and costs. Benefits were evaluated by calculating plan expenditures for various travel modes, as well as the time savings resulting from the plan. The analysis looked at how these benefits were distributed across different population groups. Costs were evaluated by examining the taxes—sales, gasoline, and income—that fund most transportation expenditures and how these tax burdens fall on various populations. The underlying concept is that the share of benefits should be roughly in line with the share of costs paid.

Distribution of Plan Expenditures by Mode

The 2001 RTP will entail expenditures on a variety of modes of travel, including highways, urban rail, commuter rail, and bus. U.S. Census data indicate travel mode choice by income level. These data were used to assign a portion of the RTP expenditures (by mode) to various income groups. The data were then combined with U.S. Census data on mode usage by income category.

This analysis showed that total 2001 RTP expenditures would be distributed somewhat more heavily toward lower-income groups. However, the RTP expenditures include substantial private investments in roadways and especially in a high-speed rail system. When only the public portion of plan expenditures is considered, the distribution is even more heavily weighted toward the lower-income categories (Table 1).

Distribution of Plan Costs (Taxes)

The environmental justice analysis examined in detail the incidence, or distribution of the burden, of taxation. Sales and gasoline taxes, along with a portion of income taxes, are the primary sources of funding for the region's transportation system. However, we are in the midst of a long-term shift away from a manufacturing economy and toward a service economy, which has important implications for the future of these tax revenue streams (Figure 1).

This shift implies that the sources of public revenue are changing. Revenues from gasoline taxes may be expected to diminish as gasoline consumption drops, with fuel economy advances and increased market penetration of alternative-fuel vehicles. Revenues from sales taxes on durable and nondurable goods will also decline, as these sales constitute less and less of the economy. Figure 2 shows how the share of state tax income from sales tax continues to decline.

Moreover, the fuel tax (technically, an excise tax) and sales tax that are the foundation of transportation revenue funding inherently raise equity concerns for lower income groups. Whereas sales taxes are, by definition, a percentage of the price of a fairly broad range of taxable goods, excise taxes are imposed on a narrow band of goods. Excise taxes are typically based on volume rather than price, for example, per gallon, per pack, and so forth. So better-off people pay the same absolute tax on expensive premium beer, cigars, or gasoline as low-income families pay on generic varieties. As a result, excise taxes are the most regressive kind of taxes.

Because graduated tax rates are almost impossible in a sales tax system, sales tax inevitably takes a larger share of income from low- and middle-income families than from high-income families. Thus, while a general sales tax may appear to be a flat-rate tax, its practical impact is different. Since the sales tax effectively exempts all unspent income, and since the rich are able to save a much larger portion of their incomes than are middle-income families (while the poor can rarely save at all), the tax is inherently regressive.

Sales and excise taxes are the main regressive element of most state and local tax systems. Spending as a percentage of income falls as income rises, and upper-income people tend to spend more on services—which mostly are not taxable. California's income taxes, by contrast, are the most progressive in the country. In 1997, the highest two income quintiles together paid over 96% of the SCAG region's total income tax, while earning only 80% of the total adjusted gross income (AGI) of the region. The highest income quintile alone contributed over 85% of the region's total income tax, while earning only about 61% of gross income. The two lowest-income quintiles earn about 10% of the region's total AGI, while contributing a negligible percentage of the region's income tax.

The combined burden of state sales, fuel, and income taxes still falls most heavily on the lowest-income group; overall, the burden ranges from a high of 16% of AGI for the lowest-income group, to a low of about 9% for the highest-income group (Figure 3).

It is important to remember that the tax burdens shown here are actual tax payments for the region as a whole. They are not the specific taxes that will directly fund the projects that constitute the 2001 RTP, though expenditures in the RTP can be expected to be funded at least in part by these taxes.

TABLE 1 Share of 2001 RTP Expenditures by Annual Household Income Category

	Less than $12,000	$12,000 to $24,999	$25,000 to $49,999	$50,000 to $69,999	$70,000 and above
Total Expenditures	29.7%	19.3%	18.6%	13.0%	19.5%
Public Portion	34.2%	21.4%	17.7%	11.3%	15.3%
Percentage of Region's Households[a]	15%	18%	32%	19%	16%

[a]Based on 1990 Census; assumed to be the same in 2025.

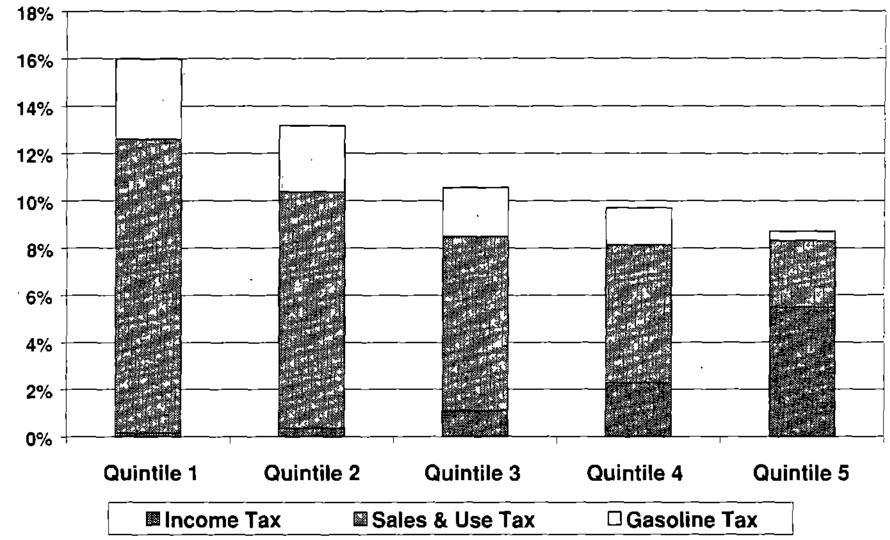

FIGURE 3 Tax burdens (taxes as percentage of adjusted gross income), SCAG region, 1997.

Distribution of Time Savings

For the 2001 RTP, transportation modeling results were used with data on mode choice by ethnic group and income group to determine travel time savings for these subpopulations. Results were calculated for trips made by automobile, for trips made by low-cost transit (such as bus and urban rail), and for trips involving all types of transit (including higher-priced options such as commuter bus and rail, or future high-speed rail). This distinction was made because the fares and service of some of the region's transit options may not be accessible by low-income riders.

For the plan overall, the share of time savings is generally in line with each group's share of trips made and share of taxes paid. For example, the share of taxes paid by the highest-income quintile would somewhat outweigh that group's share of time savings under the 2001 RTP (Table 2).

When transit modes are considered separately, there are some differences between the share of time savings and the share of burdens borne (i.e., taxes paid). (Note that the share of taxes paid is the same; tax burdens were not separated by mode.) Transit users in the lowest-income quintile pay less than 10% of total sales and gasoline taxes collected in the region, but they make more than 20% of trips by low-cost transit and will enjoy more than 25% of the time savings realized from the 2001 RTP investments. When the two lowest income quintiles are considered, the share of taxes paid is just more than 20%, but the share of benefits is close to 60% and exceeds the share of trips made (Table 2).

TABLE 2 Time Savings Due to 2001 RTP by Income Group

	Share of Total Time Savings	Share of Total Trip Making	Share of Total Sales & Gasoline Taxes Paid
All Travel Modes			
Q1[a]	8.4%	7.2%	8.7%
Q2	15.1%	15.0%	13.3%
Q3	21.9%	21.0%	17.7%
Q4	28.2%	28.0%	24.3%
Q5	26.3%	28.8%	36.0%
Low-Cost Transit[b]			
Q1	26.8%	23.1%	8.7%
Q2	30.6%	29.5%	13.3%
Q3	20.9%	22.2%	17.7%
Q4	14.7%	16.5%	24.3%
Q5	7.1%	8.8%	36.0%

[a]Q1 is the lowest income quintile; Q5 is the highest.
[b]Refers to low-fare local bus and urban rail systems.

ACCESSIBILITY ANALYSIS

Determination of Accessibility

Access or accessibility refers to the opportunity to reach a given destination within reasonable time and costs, or without being impeded by physical, social, or economic barriers. Accessibility represents the potential for both social and economic interaction. It is determined by the spatial distribution of potential destinations; the ease of reaching each destination; and the magnitude, quality, and character of the activities at the destination sites.

Travel costs are central: the less travel that costs in time and money, the more places can be reached within a certain budget and the greater the accessibility. Having a choice of destinations is also crucial: the more destinations, and the more varied the types of destinations, the higher the level of accessibility. Ideally, transportation and land use measures should be combined to ensure minimal travel time and cost.

Accessibility is determined by both patterns of land use and the nature of the transportation system. The concept of accessibility acknowledges that the demand for travel is derived from the demand for activities.

In contrast, mobility is the ability to travel and the potential for movement. It reflects the spatial structure of the transportation network and the level and quality of its service. Mobility is determined by such characteristics as road capacity and designed speed and, in the case of automobile mobility, by how many other people are using the roads.

As a planning goal, accessibility has two crucial advantages over mobility. First, it allows for evaluation of trade-offs between land use and transportation policies and focuses attention on the level of serresult of chemical interactions, photochemical reactions, and meteorology (volatile organic compounds, or VOC, and nitrogen oxides, or NO_x, and SO_x).

Emissions estimates for the plan and baseline were generated using the Direct Travel Impact Model (DTIM), which processes data produced by SCAG's regional transportation model. This methodology conservatively assumed that all residents in a given TAZ are equally exposed. Generally, both CO and PM_{10} tend to have an impact on those located closest to the source of emissions. Thus, in a TAZ containing a roadway, those closest to the roadway could experience greater emissions and potential health impacts than those located further away. This differential as it might exist within TAZs was not addressed by SCAG's analysis. Notwithstanding these assumptions, the methodology presents a reasonable gross measure of air quality impacts of mobile sources in the region.

Criteria Pollutants

Impacts for criteria pollutants (PM_{10} and CO) were determined as the change in population-weighted average emissions exposure for each TAZ, averaged across all the modeled TAZs. Emission estimates for each TAZ were divided by the TAZ's land area so as to normalize emissions. Emissions exposures were thus expressed in kg/day/km^2. Emissions of dust associated with roadway use were not included as part of this analysis.

Overall, the region will experience a decrease in CO emissions and in vehicular PM_{10} emissions. Because this is the case, all groups in the region will also experience a decrease and there is no significant impact, in the sense indicated by environmental justice guidance. Generally, the decreases experienced by the demographic groups of concern for environmental justice are at least as large as those experienced by all persons in the SCAG region. Figure 5 compares the decreases in CO emissions exposure (plan versus baseline) experienced by various income groups. The reductions in vehicular PM_{10} show a very similar pattern, though they are smaller in magnitude.

Air Toxics

Also of interest are potential health effects resulting from so-called air toxics—pollutants from mobile sources that are not regulated by federal or state air quality standards but that may have localized effects. A recent modeling and monitoring study by the South Coast Air Quality Management District (*4*) indicated that 90% of cancer risk from air pollutants in the air basin arises from mobile source emissions. Furthermore, the study found that 70% of cancer risk is attributable to diesel particulate.

SCAG's DTIM modeling results allow the separate estimation of particulate exhaust emissions from heavy-duty vehicles. Considering these data to be the closest approximation to the diesel particulate implicated in the district's study, the foregoing analysis was repeated using only these emissions data. The results are very similar to those found for the CO and vehicular PM_{10} analyses. All groups will experience a decrease in emissions exposure, and most groups of concern from an environmental justice perspective will experience a greater decrease than the region as a whole (see Figure 6 for ethnic groups, the elderly, and the disabled).

Noise

SCAG's analysis of noise considered two sources: aviation noise (from aircraft at the region's airports) and highway noise. Although other transportation modes, such as trains, also create noise, insufficient data were available to analyze these impacts. Because of differences in data sources and noise standards, SCAG could not combine the data to estimate aggregate noise impacts of the plan.

Aviation Noise

Projected noise impacts from aircraft operations at the region's airports in 2025 were modeled using the FAA standard Integrated Noise Model. For each airport, modeling produced a contour for the 65 dB community noise equivalent level (CNEL), a measure of noise that takes into account both the number and the timing of flights as well as the mix of aircraft types. The FAA considers residences to be an incompatible land use with noise at or above this CNEL level.

SCAG identified populations that might be affected by noise, using a geographic information system (GIS) to delineate the 65 dB noise contours around each airport, as projected for 2025. The affected population within the contour was calculated by applying the percentage of residentially zoned land lying within the contour to the total population of each TAZ that fell entirely or partially within the contour. Proportions of the environmental justice populations of interest (e.g., minorities, elderly) were similarly calculated based on the TAZ data. The total (systemwide) demographics of the people affected by noise above 65 dB were calculated by adding the numbers of people (or households, in the case of income) affected at all the airports in the analysis.

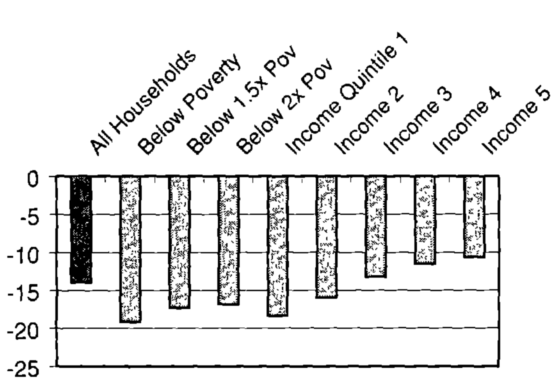

FIGURE 5 Weighted average CO emissions exposure change: plan versus baseline, 2025 (kg/day/km^2).

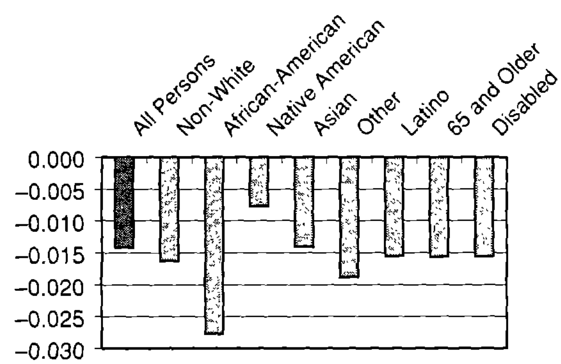

FIGURE 6 Weighted average heavy-duty vehicle PM_{10} exhaust emissions exposure change: plan versus baseline, 2025 (kg/day/km^2).

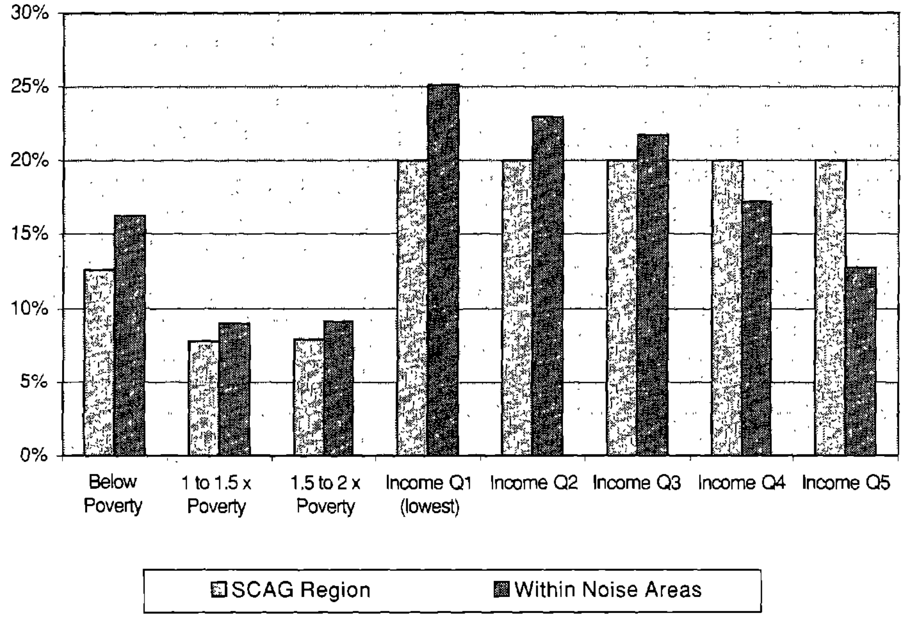

FIGURE 8 Income level of households affected by aviation noise due to 2001 RTP compared with income level of SCAG region, 2025.

Environmental impact analyses show that air emissions and highway noise will not disproportionately affect minorities, low-income people, the elderly, or the disabled. Again, it is important to keep in mind that the region as a whole will experience overall air quality improvements due to ongoing mobile source emission controls and investments in the RTP. Only the aviation noise analysis indicates that minority and low-income persons may be disproportionately affected, based on a systemwide analysis. The selection of a regional aviation scenario that distributes (decentralizes) aviation demand to all the region's airports will minimize this disproportionate impact.

SCAG's analyses indicate that the RTP will not place a disproportionate burden of impact or cost on those least able to afford it. Although the analyses were designed to examine different facets of the plan, including service equity, tax burdens, and the distribution of environmental benefits and lack of benefits, they represent only one possible set of approaches to the question of equity in transportation planning. Furthermore, they raise important questions for further study, at least in the SCAG region.

ACKNOWLEDGMENTS

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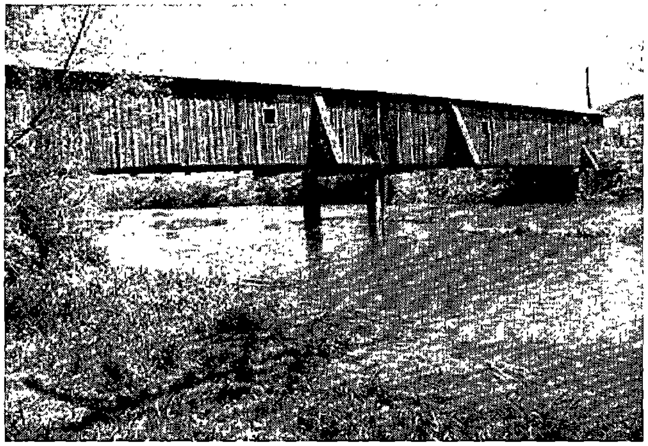

FIGURE 1 Preconstruction view of the Hamden Covered Bridge.

FIGURE 2 How not to relocate a covered bridge for repair work.

gram of $2 million a year. Hence, this amount of investment for the county is very significant. This type of work is not inexpensive.

ENGINEERING AND CONSTRUCTION CHALLENGES

How to, and How Not to, Move a Covered Bridge

This discussion deals with the most dramatic issue with this bridge project—an incident that was regrettable, yet not catastrophic. Yet the incident can be instructive, and the following section attempts to briefly summarize relevant issues.

The West Branch of the Delaware River can rise rapidly during times of heavy rain. It is also a highly regulated waterway and trout stream. Therefore, working over the water would present special challenges. Accordingly, the contractor (W. L. Kline, Inc., of Cortland, New York) chose to relocate the span to its southern approach roadway section for the reconstruction process. The construction documents contained no objection to such a move. The documents required engineering sketches and calculations addressing the proposed means for support of the bridge during its reconstruction. Hence, engineering information was required for the relocation.

Kline had previously completed the successful reconstruction of another covered bridge owned by Delaware County—the Downsville Bridge, a 170-ft (51.9-m) long bridge built by Robert Murray, the same builder as the Hamden Bridge—also using a Long truss configuration, but supplemented with a stiffening arch. That project had gone well, and Kline had demonstrated great skill and care with that work. The company has an excellent reputation for construction work, including repairs of historic structures made of timber.

Kline proposed to relocate the bridge using a pair of heavy cranes, one on each shore, but had not presented engineering support for the work. The county Department of Public Works (DPW) decided to allow the move to proceed, albeit with some trepidation. Unfortunately, the move culminated in an incident that effectively broke the bridge into two pieces and dropped them into the river (Figure 2).

Several issues contributed to the failure. First, the reach and capacity of the cranes were limited such that they could not pick the bridge from its ends and move the bridge in one operation. It was decided to pick the bridge in several panels from the end of the bridge as a means to gain more reach and capacity. Unfortunately, this caused the cantilever ends of the bridge to exert forces on the cantilever portions of the truss opposite from its design condition—that is, the top chord, designed for compression, was expected to support tension and the bottom experienced the opposite situation. The initial failure of the bridge occurred at the top chord at the pick point, where subject to the maximum tensile stresses.

As an engineering observer not in control of the project (the contractor had control and was positioned at the cab of one of the two cranes), DPW could have stopped the work and assumed responsibility for the project. DPW chose not to take that step, since it would have exposed DPW to unacceptable liability issues. DPW expected the contractor to suspend the shift of the bridge, once having moved it such that the original abutment end was located over the central pier bent to allow a relocation of the pick points. However, the contractor was unwilling to do so, in large part due to the unknown nature of the lateral capacity of that bent to safely support the end of the bridge, while the bridge was positioned on an inclined plane cantilevered over the far abutment. So the contractor decided to keep going past that bent. With the far crane at its maximum reach, there was an unexpected change in the balance of load between the two cranes, and the truss failed. (Kline never asked for more money as a result of this event, and DPW maintained an excellent working arrangement during the work.)

Fortunately, no one was hurt during this incident, and ultimately, the damage to the bridge did not involve many components beyond those already identified for replacement for other reasons. The county shared in the blame in that DPW did not insist on the engineering support before the work.

Progress in Reconstruction

The reconstruction of the bridge proceeded through the summer and fall. When ready to relocate the bridge back to its reconstructed foundations, the county insisted on the use of a roller system supported on false work, another common practice in the relocation of covered bridges. A lack of confidence in the ability to use cranes to move a covered bridge was not the point, but the community would have been in an uproar had they observed cranes coming in for the resiting. DPW was unwilling to deal with the media circus that the situation would have caused.

The false work system included a pair of longitudinal steel beams positioned directly beneath the trusses of the covered bridge. The tory term—elephant ears—because they are evidence of an unwillingness to make the internal bracing system do its job. It is unclear if these external braces were original at the time of construction or added later when the bridge exhibited distress (refer to Figure 1 and note the external braces).

The original roofline is relatively shallow on the Hamden Bridge and offers little room to improve the internal bracing system. Again, in large part following the work performed at the Downsville Bridge, the roof of the Hamden Bridge was removed to allow replacement by a more conventional sloped roof with more space to install a substantial internal bracing system. The tie beams were joined with oversized rafters and knee braces of sufficient size and connection strength to maintain the stability of the bridge. This modification to increase the lateral support of the bridge has been quite common on numerous recent covered bridge rehabilitation projects for a variety of owners, by covered bridge engineers faced with the responsibility of providing a safe structure.

High-end web member stresses were also a factor. Before this rehabilitation of the bridge, several of the members at the end of the trusses exhibited significant distortion and overstress (Figure 6). A careful look at the photograph shows that the top of the vertical post is cracked above the upper right bolt. Also note the general bend of the vertical to the right. The knee brace is in the foreground, connecting to the tie beam just out of the top of the photograph. The pair of main diagonals is on the right, and the counter is on the left. The reconstruction of the bridge replaced these split posts with heavier members.

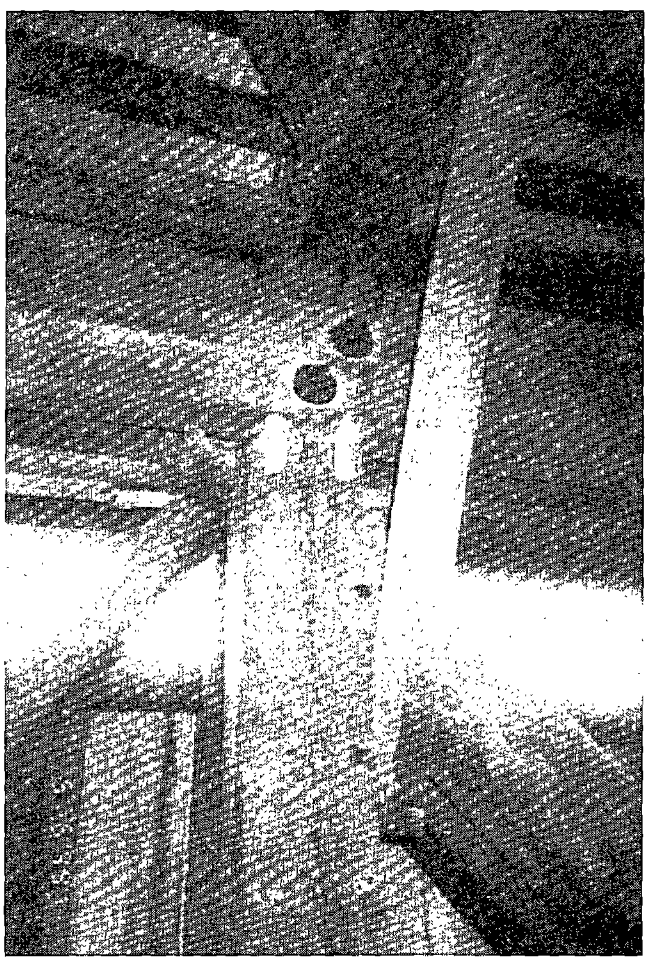

FIGURE 6 Diagonal to post connections at the top chord indicating significant overstress.

MYTH AND REALITY OF COLONEL LONG'S WEDGES

One of the interesting aspects to the patent application of Colonel Long was provision of wedges at the connection between vertical post and chord. See the left side of the right post in Figure 7. The value of the wedges is principally to distribute the high side-grain bearing stresses in the post to a larger area. Quite a bit has been written about these wedges. They have been attributed as the precursors of posttensioning systems that have become commonplace in the second half of the 20th century. An often-used diagram to demonstrate their function is with a two-panel truss. It is fascinating to delve into this issue a little more and find that whereas the two-panel truss can be manipulated to demonstrate a posttensioning effect from the wedges, a truss with more panels cannot so support the concept.

Instead of pursuing this aspect further, the other advantages of the wedges will be considered. The interface of the vertical members and chords is one with very high side-grain compression in the vertical against end-grain compression in the chord. These forces are the direct consequence of the horizontal component of load in the diagonal members as they are transferred to the chords in axial load. A thorough review of the stresses of the joints of the Hamden Bridge indicates that the wedges play an important role in distributing the stress to the post over a greater area to effectively reduce the side-grain compression. It is conceivable that Colonel Long recognized the advantage of the wedges in this way.

However, there is another twist to this issue. Some Long trusses were built with wedges in both top and bottom chords, whereas others (like Hamden) were built with wedges only in the bottom chord. The side-grain bearing issue is just as important in the top as in the bottom. Hence, the assumption that Long recognized this strength is counteracted by leaving them out of the top chords. The wedges are easily visible in the top chord connections, while the bottom chord wedges are hidden beneath the floor beams and a careful inspection from below is necessary to observe them.

It would be interesting to inspect all remaining Long truss bridges (there are only about 25 extant covered bridges that are supported by some variation of a Long truss) to compare the use of wedges against their date of construction to see if the use evolved. Of course, it must

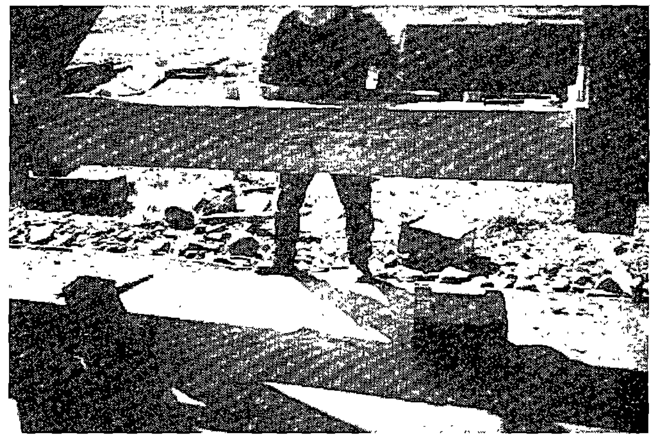

FIGURE 7 Colonel Long wedges in the bottom chord used in the connection between the vertical post and chord.

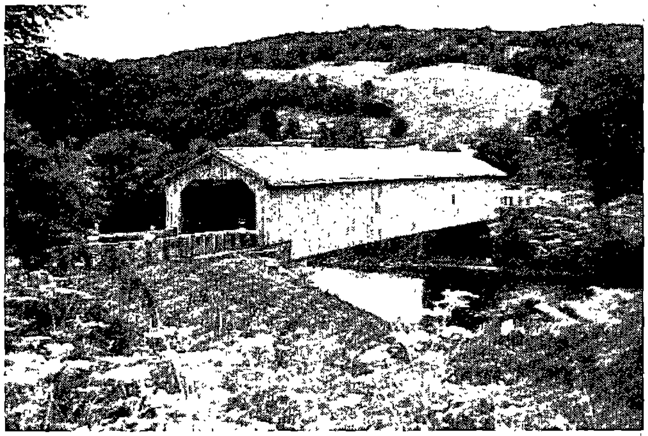

FIGURE 9 Final exterior view.

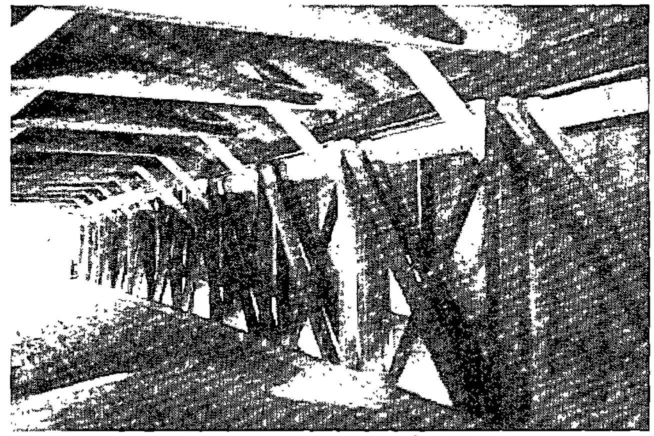

FIGURE 10 Final interior view.

members shown in Figure 10. Kline's contract was for $558,000, and the county incurred about another $150,000 for the work as cited, along with the costs of engineering and inspection support. That is a lot of money to spend on a single-lane, single-span bridge, yet it is in keeping with the varied prices of work on covered bridges. The cost of such work depends on the geographic location of the project and proximity (or lack thereof) to contractors experienced with work on covered bridges, as well as the contractor's workload for this type of specialty work. This makes it very difficult to predict costs for such work, because what might be bid as $500,000 in one area and time, might be bid as half that, or twice that, in another area and time. However, it should be kept in mind that the federal government has passed legislation (the before-mentioned NHCBPP) that allocates up to $50 million on the approximately 880 extant historic covered bridges in the United States. Hence, the government supports this work, expensive as it is, for its merits at preserving these deserving monuments to our bridge building heritage.

SUMMARY AND CONCLUSIONS

This covered bridge rehabilitation project confronted many of the unusual and difficult issues common to covered bridge work. From the difficulties related to removing the superstructure to allow reconstruction of the abutments to dealing with the shortcomings of current specifications related to conservative allowable stresses for proven older timber components, projects such as this are continually challenged to yield a rehabilitated structure safe for vehicular passage, while minimizing replacement of structure components. Although this project was not officially sponsored by the NHCBPP, the planning, design, and construction were performed to similar standards. In the case of the Hamden Covered Bridge, the increases in strength gained by the improved internal bracing, the use of metal roofing to shed snow loads more quickly, and improvements in the truss details (e.g., adding the wedges to the top chord and oversizing connector holes) allowed the bridge to remain open to vehicular traffic.

It should be noted that the planning and design of the project went through all required permitting processes, including extensive coordination with the State Historic Preservation Office (SHPO). That office had been involved with the work performed earlier at the Downsville Covered Bridge and some of the same issues were involved in this work. More component replacements were required at the Hamden Bridge due to its advanced state of deterioration and high stresses, which culminated in a meeting on site with SHPO representatives. Although some members of the local community felt that too many members were replaced, the SHPO representatives confirmed what DPW had understood from leaders of national organizations. Senior representatives of the National Historic Trust, the Historic American Building Survey/Historic American Engineering Record, and FHWA, indicated that current historic preservation practice had evolved past a simple focus on the percentage of member replacement. Current focus is more on the types of members to be replaced and the engineering justification for their replacement. A strong indication of the success of the project was gained by receipt of a letter from SHPO conveying its support of the work, after a field review, by reiteration of its determination of "no adverse effect."

ACKNOWLEDGMENTS

The author acknowledges the Delaware County Department of Public Works (DCDPW) for the opportunity to share this information. The author also acknowledges the contributions of David Fischetti of Cary, North Carolina, who performed the initial engineering on this project.

In addition to his consulting engineering practice, the author is employed by the DCDPW as deputy commissioner in charge of engineering and performed the engineering associated with this project as an employee. The author served as engineer in charge during the reconstruction, completed the work, and was responsible for the final product.

Publication of this paper sponsored by Committee on Historic and Archeological Preservation in Transportation.

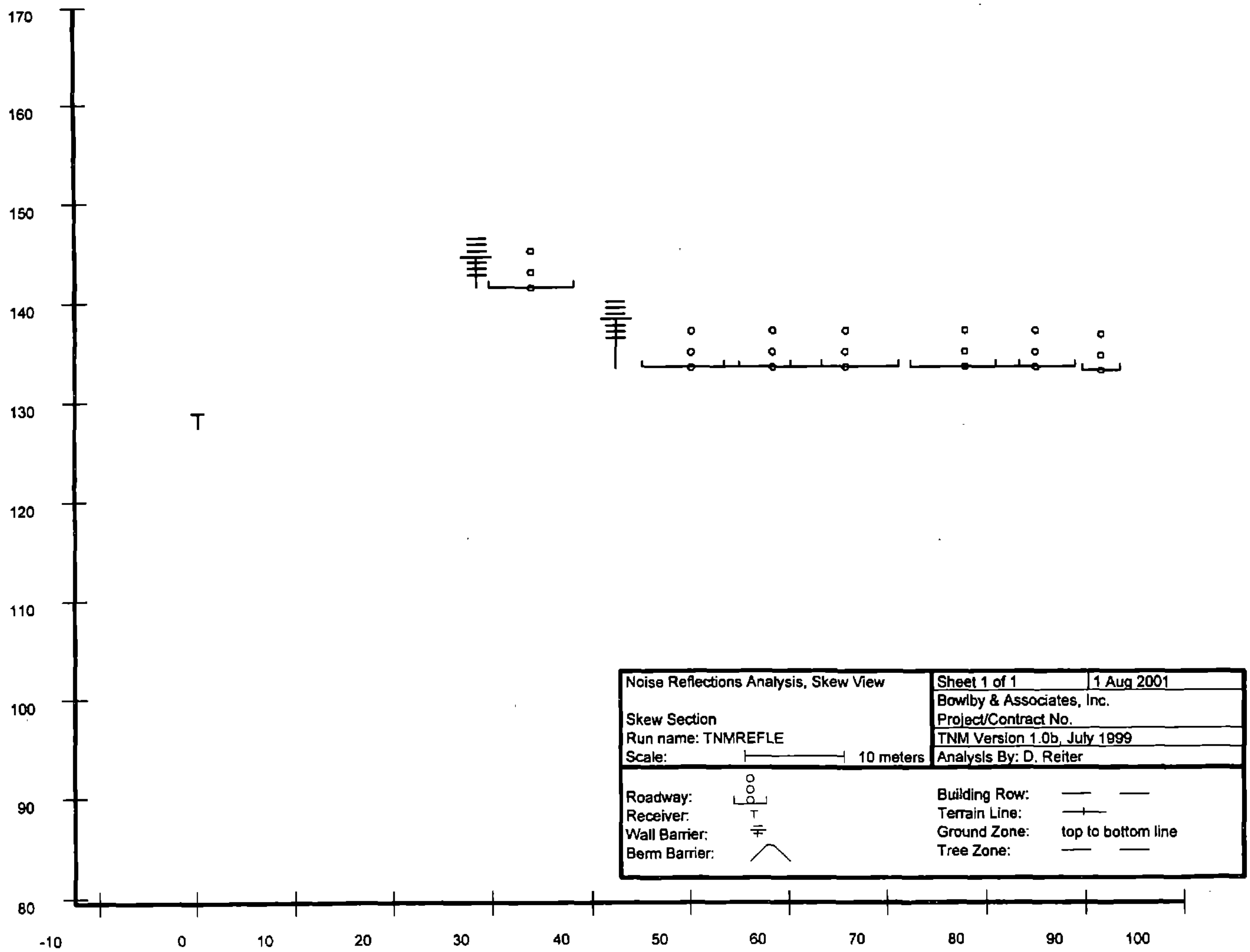

FIGURE 1 Sample Traffic Noise Model skew view.

analyzing the skew views, it is helpful to hide these terrain lines. To accomplish that, the analyst selects the "View" menu bar from the main TNM tool bar and selects "Show/Hide." A dialogue box will appear. In the "Show Objects" column, the analyst must click on the box for terrain lines and then click the "OK" icon. The terrain lines will disappear.

Figure 2 shows the locations of several residences located near a proposed elevated bridge structure for a ramp. This area is the subject of the case study presented in the following report section. Figure 3 shows the TNM plan view of the noise model for this area and shows the locations of the analyzed skew views for Receiver 2 (Rec 2) in the file. Figure 4 shows skew view No. 4 from Figure 3, and Figure 5 shows skew view No. 6 from Figure 3.

Before generating the skew views, the analyst should ensure that the elevated bridge structure is modeled properly for the analysis. When modeling the elevated roadway in the base TNM model to predict 1-h equivalent sound levels without consideration of noise reflections, the roadway would typically be modeled in the center of the travel lane(s). The roadway width would then be set to properly model the location of the outside edge of bridge structure. As a result, the modeled width may not match the actual width of the bridge structure for the roadway. For example, the pavement width for an elevated one-lane roadway that has a single 3.6-m travel lane, a 3-m outside shoulder, and a 1.2-m inside shoulder would be 7.8 m. However, the modeled pavement width in TNM would be determined by taking the distance from the modeled roadway to the edge of the outside shoulder and multiplying this number by a factor of two. In this case, the TNM roadway width would be set to 9.6 m, or 4.8 m (half of the 3.6-m travel lane plus the 3-m outside shoulder) multiplied by two.

As a result, the modeled roadway may need to be shifted in the TNM file to the centerline of the bridge structure, and the TNM roadway width should be set to the actual width of the bridge structure. The elevation of the roadway should also be lowered to represent the elevation of the underside of the bridge structure and not the elevation of the travel lanes.

Once a set of skew views has been generated and printed for each analysis receiver, each skew view must be analyzed to determine if noise reflections off the underside of the elevated bridge structure will reach the receiver. The following steps are involved:

1. Draw a horizontal line from the elevated structure to a point above the modeled receiver;
2. Locate an image receiver above the horizontal line drawn in Step 1; and

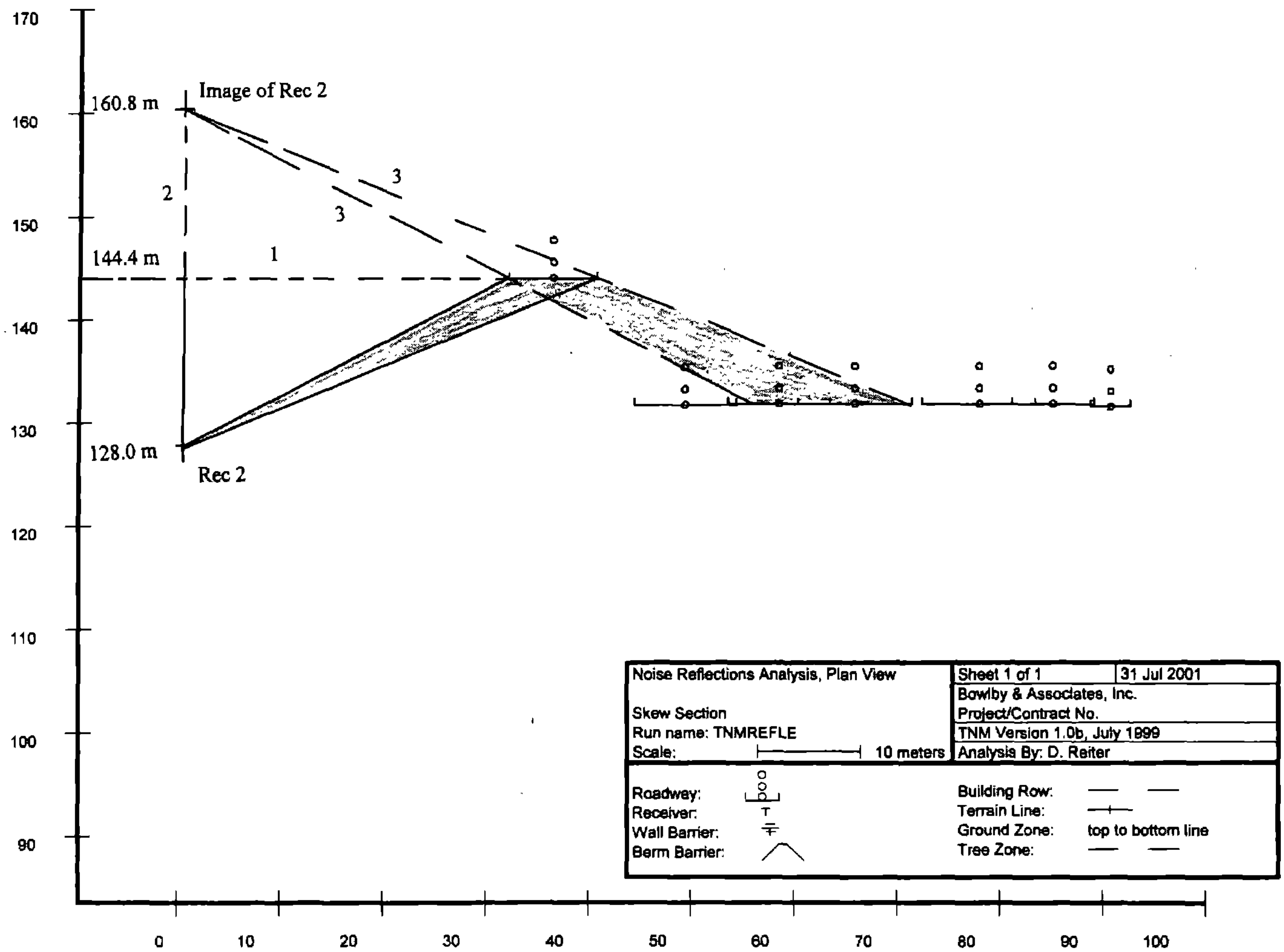

FIGURE 4 Traffic Noise Model skew view No. 4 for Rec 2.

3. Draw lines from the image receiver through each of the outside edges of the elevated bridge structure until these lines intersect the ground. The horizontal distance between the two lines indicate the location from where noise reflections would originate if a noise source were located there. As a result, if a roadway(s) is located in this area, then traffic noise from this roadway section would be expected to reflect off the underside of the elevated bridge structure and reach the receiver.

These steps are indicated by the Nos. 1 through 3 on the skew views in Figures 4 and 5. As shown in Figure 4, traffic noise from two of the roadways will reflect off the underside of the elevated bridge structure and reach Rec 2, whereas traffic noise from the other four roadways will not.

Similarly, the skew view shown in Figure 5 indicates that traffic noise from the outside roadway will reflect off the underside of the elevated bridge structure and reach Rec 2, whereas traffic noise from the other roadways will not.

As indicated in the skew views in Figures 4 and 5, TNM has three separate source heights for automobiles, medium trucks, and heavy trucks. The reflection path may include only one or two of these source heights for a particular roadway segments. For this procedure, it is assumed that noise from all three vehicle types on an identified roadway segment would reflect off the underside of the elevated bridge structure if the reflection path intersected the pavement.

The number of skew views required may vary from receiver to receiver depending on the geometry involved. Once a first set of skew views is analyzed, as described later, the analyst may generate and analyze additional skew views to gain a better understanding of the extents of the roadway segments from which noise reflections will originate.

After all of the skew views have been analyzed, the analyst can identify those roadway segments from which traffic noise will reflect off the underside of the elevated bridge structure and reach the receiver.

The analyst creates a separate TNM file for each receiver with only those roadway segments from which reflections will originate and the image receiver. The image receiver is located at the image height above the ground, as shown in Figures 4 and 5. Modeling the image receiver ensures hard site propagation from the traffic on the roadways to the receiver.

The TNM plan view in Figure 6 shows the segments from which noise reflections will originate and reach Rec 2.

TNM is then run to determine the noise reflection contribution at each of the analysis receivers. This TNM-predicted noise reflection contribution is then added to the predicted no-barrier 1-h equivalent sound levels at each receiver to determine actual no-barrier 1-h equivalent sound levels.

If a barrier is proposed for the area, the analysis needs to be repeated for the with-barrier condition if the noise barrier will block some or all of the noise reflections. If the barrier will not block the noise reflections, then the reflection noise contributions for the with-barrier case are the same as for the no-barrier case.

For the with-barrier case, the noise reflection contribution is added to the with-barrier 1-h equivalent sound level without consideration of reflections to arrive at the actual with-barrier 1-h equivalent sound level. The barrier insertion loss (IL) with reflections is then recalculated by subtracting the with-barrier 1-h equivalent sound level with reflections from the no-barrier 1-h equivalent sound level with reflections. The barrier degradation in terms of reduction in IL can then be determined by subtracting the predicted barrier IL without reflections from the predicted barrier IL with reflections.

As stated, this procedure is intended for use at a screening level of analysis. Each site will vary and may have unique considerations, including the type of bridge structure (e.g., box beam, steel girder), multiple reflection paths, superelevated bridge structures, and stop-and-go traffic conditions. In these cases, the analyst may opt to complete a more detailed analysis.

CASE STUDY

The Tennessee Department of Transportation (TDOT) will be widening Interstate 40 (I-40) and reconstructing the interchange of I-40 and Robertson Avenue/Briley Parkway in Nashville. The proposed interchange will include four levels and will involve the construction of several elevated bridge structures for ramps near noise-sensitive land uses adjacent to the interchange.

A detailed noise analysis was completed for the project, using TNM. The design year was 2019. Several areas of noise-sensitive land use were identified and analyzed.

The review of the locations of the elevated bridge structures for the noise analysis indicated that main-line traffic noise might reflect off the underside of some of the elevated bridge structures and reach residences in these areas.

Of particular concern was the elevated bridge structure for the ramp from eastbound I-40 to northbound Briley Parkway. The bridge structure is located approximately midway between the I-40 main line and several first-row residences on the north side of I-40 as shown in Figure 2. I-40 is on a slight fill through this area and the ramp structure is elevated 12 to 20 m above the residences. I-40 is approximately 50 m wide through this area, so reflection paths from some of the roadways to the receivers were expected.

The procedure described above was used to assess whether noise reflections would increase no-barrier 1-h equivalent sound levels for these residences. Additionally, a noise barrier for this area was determined to be both feasible and reasonable in accordance with TDOT's noise policy (2) without consideration of the noise reflections. As a result, the effect of the noise reflections on the barrier's effectiveness was also completed.

Table 1 presents the analysis results. As shown, predicted no-barrier 1-h equivalent sound levels at the three modeled first-row receivers without consideration of the noise reflections off underside of the elevated bridge structure are in the range of 72 to 76 dBA. The predicted no-barrier 1-h equivalent sound levels at the three modeled second-row receivers are in the range of 69 to 72 dBA.

The term IL is generally used to describe the reduction in 1-h equivalent sound level at a location after a noise barrier is constructed. For example, if the 1-h equivalent sound level at a residence before a barrier is constructed is 75 dBA and the 1-h equivalent sound level after a barrier constructed is 65 dBA, then the IL would be 10 dB.

The noise barrier for the area was designed to provide an IL of 7 to 10 dB for affected first-row receivers resulting in with-barrier 1-h equivalent sound levels around 65 dBA. The barrier was 4.5 to 5.0 m high.

In this case, the noise barrier would not block the reflection paths from the roadways to the receivers. As a result, the noise reflection contribution shown in column five of Table 1 is the same for the no-barrier and with-barrier cases. As indicated, the noise reflection contribution is between approximately 71 and 73 dBA for the modeled first-row receivers and between 69 and 73 dBA for the modeled second-row receivers. These contributions equal or exceed the predicted no-barrier 1-h equivalent sound level at one of the three first-row receivers and at all three second-row receivers. These higher noise contributions result from hard-site propagation of the noise reflections off the underside of the elevated bridge structure. Additionally, I-40 is on fill through the area. As a result, the edge-of-pavement of I-40 provides shielding for the modeled receivers from I-40 traffic noise. The noise reflected off the underside of the bridge structure, however, is not shielded.

This noise refection contribution in column five of Table 1 was added to the no-barrier and with-barrier 1-h equivalent sound levels in columns two and three to arrive at the no-barrier and with-barrier 1-h equivalent sound levels with reflections in columns six and seven.

The with-barrier 1-h equivalent sound levels at modeled first-row receivers are increased by 6 to 9 dB, resulting in with-barrier 1-h equivalent sound levels of 72 to 74 dB. As noted previously, the barrier would not block the reflection path from the roadways to the receivers. Thus, the noise reduction provided by the main-line barrier

TABLE 1 Noise Reflections: Analysis of Results

Receiver	Analysis Results without Reflections			Reflections Contribution (dBA)	Analysis Results with Reflections			Insertion Loss Degradation (dB)
	"No Barrier" L_{Aeq1h} (dB)	"With Barrier" L_{Aeq1h} (dB)	Insertion Loss (dB)		"No Barrier" L_{Aeq1h} (dB)	"With Barrier" L_{Aeq1h} (dB)	Insertion Loss (dB)	
First-Row Receivers								
Rec 1	76	66	10	71	77	72	5	-5
Rec 2	72	65	7	73	76	74	2	-5
Rec 3	72	65	7	71	75	72	3	-4
Second-Row Receivers								
Rec 4	72	65	7	73	76	74	2	-5
Rec 5	70	64	6	71	73	71	2	-4
Rec 6	69	64	5	69	72	70	2	-3

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Comparison of Measured and Modeled Sound Levels in the Vicinity of Traffic Noise Barriers

Roger L. Wayson, John M. MacDonald, Wayne Arner, Winfield M. Lindeman, and Mariano Berrios

A detailed noise prediction model was used to compare 11 highway noise barrier locations in Florida. Insertion losses, ground effects, shadow zones, and overall trends were determined or analyzed, or both. Each location was modeled using STAMINA2.0 (current FHWA regulatory model), STAMINA2.1 (Florida's version of STAMINA2.0 with state-specific emission levels), the Traffic Noise Model (often referred to as TNM; this model will replace STAMINA2.0 in the year 2002), and the University of Central Florida Community Noise Model (CNM5.0). The modeled results were then statistically compared with the measured results. Statistical evaluation results were similar for all models for overall, absolute prediction compared with the measured value, with STAMINA2.1 being slightly better. All models provided adequate results, but ranges of error were significant. When the propagation components were explored, by comparing reference levels with those behind the barrier, the TNM was significantly better. The results also provided further insight into the benefited regions behind the barrier, a more detailed understanding of how the models perform for this complex interaction with the ground and sound wave, and how background levels change the actual size and shape of the benefited region.

Although other noise abatement measures exist and are used, noise barriers are the most common method used to abate sound levels from highways in North America. Exacting models are needed to accurately predict the true insertion loss or noise reduction that occurs when using a noise barrier for a highway project.

Noise measurements were made at 12 locations in Florida to evaluate barriers near heavily traveled roadways. At each location, sound levels were measured at various heights and distances behind the barrier at a minimum of 12 positions. Both one-third octave band and overall A-weighted levels were measured. During quality control, one location was not acceptable for barrier evaluation and not used. The complete data collection effort and collected data, including barrier locations and heights, are discussed in a companion report, available from the authors. The measurements provided a reference data set to compare with modeled results using the noise prediction programs. The computed data included

- Prediction of sound levels at specific positions,
- Calculation of insertion losses,
- Shadow zone evaluations, and
- Overall trend analysis of the collected data.

Because the noise barriers evaluated were already in place, the American National Standards Institute (ANSI) S12.8 standard method (*1*) was used to determine insertion loss. This analysis permitted conclusions to be drawn on the trends and accuracy of the evaluated models. This report details the methodology used during the analysis and the conclusions based on the analysis.

Using the carefully quality controlled measured noise levels, four models were evaluated:

1. The Traffic Noise Model (TNM) (*2*),
2. STAMINA2.0 with national reference energy mean emission levels (REMELs) (*3*),
3. STAMINA2.1 with Florida specific emission levels (*4*), and
4. The University of Central Florida Community Noise Model (CNM5.0) (*5*).

These models were selected for the following reasons:

1. The TNM is being phased in at this time to replace STAMINA2.0, the current regulatory model;
2. STAMINA2.1 is the current regulatory model in Florida varying only by the REMELs from STAMINA2.0; and
3. CNM employs a true simulation approach, different from the static line sources used in the other models.

It must be noted that there are significant differences between the models. To determine the important diffraction effects used to determine the barrier attenuation, the Kurze and Anderson approach is used in both STAMINA2.0 and STAMINA2.1. The International Organization for Standardization (ISO) 9613 standard (*6*) used in CNM is based on the Kurze and Anderson (*7*) model along with a term that adjusts for downwind propagation conditions that degrade the barrier performance. A variation of the DeJong et al. (*9*) and Pierce (*10*) approach is used in the TNM. Table 1 lists the diffraction methods used in the noise prediction computer models evaluated in this report. Other differences in the models included the following:

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TABLE 2 Predicted and Adjusted Insertion Losses

Location	Microphone Position	TNM IL L_{Aeq}	ST2 IL L_{Aeq}	TNM-ST2 L_{Aeq}	Difference (Pred- Meas) L_{Aeq}	Adjusted TNM IL L_{Aeq}	Difference TNM_{adj}- ST2 L_{Aeq}
A	1	9.7	7.1	2.6	2.7	7.0	-0.1
	2	11.0	6.3	4.7	2.2	8.8	2.5
	3	10.9	4.8	6.1	4.6	6.3	1.5
	4	12.2	8.9	3.3	NA	NA	NA
	5	13.2	7.5	5.7	4.0	9.2	1.7
	6	11.6	5.0	6.6	3.3	8.3	3.3
	A	14.3	9.4	4.9	4.0	10.3	0.9
	C	10.7	7.8	2.9	3.5	7.2	-0.6
B	1	8.7	6.3	2.4	3.4	5.3	-1.0
	2	8.6	4.4	4.2	4.2	4.4	0.0
	3	5.4	1.8	3.6	0.1	5.3	3.5
	4	12.0	8.1	3.9	4.0	8.0	-0.1
	5	10.7	5.2	5.5	3.5	7.2	2.0
	6	3.6	1.2	2.4	-1.9	5.5	4.3
	A	13.9	10.3	3.6	5.1	8.8	-1.5
	C	11.3	7.0	4.3	3.3	8.0	1.0
C	1	7.4	6.5	0.9	-1.5	8.9	2.4
	2	6.5	5.0	1.5	-1.5	8.0	3.0
	3	4.2	2.8	1.4	-1.3	5.5	2.7
	4	9.0	9.3	-0.3	-0.6	9.6	0.3
	5	8.5	6.8	1.7	-1.1	9.6	2.8
	6	4.9	2.9	2.0	NA	NA	NA
	A	10.0	11.9	-1.9	-0.7	10.7	-1.2
	C	9.0	7.9	1.1	0.2	8.8	1.0
E	1	9.4	7.5	1.9	1.1	8.3	0.8
	2	9.4	7.2	2.2	0.8	8.6	1.4
	3	9.3	6.4	2.9	0.5	8.8	2.4
	4	3.6	8.0	-4.4	1.4	2.2	-5.8
	5	6.0	8.6	-2.6	1.5	4.5	-4.1
	6	9.8	8.2	1.6	0.4	9.4	1.2
	A	12.0	9.7	2.3	-1.2	13.2	3.6
	C	5.5	8.0	-2.5	0.9	4.6	-3.4
F	1	5.2	4.8	0.4	2.0	3.2	-1.6
	2	5.4	2.8	2.6	-1.2	6.6	3.8
	3	4.0	1.7	2.3	1.1	2.9	1.2
	4	7.7	8.2	-0.5	1.3	6.4	-1.8
	5	7.4	5.0	2.4	-1.1	8.5	3.5
	6	2.7	1.4	1.3	-0.3	3.0	1.6
	A	10.9	10.6	0.3	0.7	10.2	-0.4
	C	6.4	6.3	0.1	2.1	4.3	-2.0
G	1	3.8	2.9	0.9	1.0	2.8	-0.1
	2	3.3	1.9	1.4	-0.6	3.9	2.0
	3	1.4	0.7	0.7	-2.7	4.1	3.4
	4	5.5	3.9	1.6	0.6	4.9	1.0
	5	2.9	2.3	0.6	-3.2	6.1	3.8
	6	-0.1	0.4	-0.5	NA	NA	NA
	A	7.3	4.8	2.5	1.4	5.9	1.1
	C	4.6	3.5	1.1	0.8	3.8	0.3
H	1	9.8	6.3	3.5	1.2	8.6	2.3
	2	9.5	4.6	4.9	2.2	7.3	2.7
	3	7.6	1.9	5.7	1.5	6.1	4.2
	4	11.8	8.9	2.9	3.0	8.8	-0.1
	5	11.4	6.0	5.4	1.1	10.3	4.3
	6	5.8	1.3	4.5	0.2	5.6	4.3
	A	13.3	11.3	2.0	2.0	11.3	0.0
	C	11.0	7.5	3.5	1.1	9.9	2.4

LEGEND: A = Jacksonville, B = Jacksonville, C = Daytona Beach, D = Sarasota, E = Brandon, F = Clearwater, G = St. Petersburg, H = Ft. Lauderdale, I = Deerfield Beach, J = Miami, K = Tamiami, and L = Hialeah.

(continued)

TABLE 4 Comparison of Reference Energy Mean Emission Levels [All Values in dB (A)]

Site	TNM	ST2.0	ST2.1	UCF CNM
A	1.6	-2.2	-1.0	0.1
B	3.0	-0.5	-2.2	1.2
C	1.0	-2.1	-1.8	0.1
E	-0.3	-3.3	-5.2	-2.0
F	1.4	-2.3	-1.0	-1.4
G	-2.1	-4.4	-2.9	-2.6
H	3.9	0.1	-1.0	0.1
I	3.6	-0.4	-1.5	0.3
J	0.3	-3.2	-2.7	0.6
K	1.5	-1.7	-0.2	-0.2
L	1.9	0.3	-1.0	-0.7

followed, some errors occurred from use of incorrect pavement type (average pavement was used instead of asphalt) and weather parameters (temperature and humidity were higher than the policy-required inputs).

The next set of testing was done to determine how well propagation algorithms performed in each model. To do this, without including the effect of the REMELs, the difference at the reference microphone positions and the microphone positions behind the barrier were analyzed. The same statistical tests were performed as with the comparison of the measured and modeled results. The results of this testing are shown in Table 5, again with the best results for any model shown in bold. In this testing, the TNM was the best in the most tests and if only the barrier design models are considered (TNM, STAMINA2.0 and STAMINA2.1), the TNM is clearly better. This finding would seem to imply that there are compounding errors that cause STAMINA2.1 to predict the best, for the TNM average error for the REMELs was better than that of STAMINA2.1, and the propagation testing also proved to be better for the TNM.

This apparent contradiction led to additional questions about the shadow zone. Shadow zones are generally thought to be the darkest (with more noise reduction) immediately behind the barrier near the ground surface. Very near the noise barrier, increases in height result in reductions to the barrier attenuation, and just after the top of the barrier the noise attenuation disappears.

The reader is asked to first consider the idealized shadow zone shown in Figure 1*a*. The dark area represents the area of noise reduction. But diffraction occurs, which is the ability of the sound to turn corners. This frequency dependent phenomenon results in a smaller shadow zone than the idealized zone. Scattering of sound and refraction also occur from the illuminated zone, further shrinking the shadow zone. As a result, the shadow zone depth is reduced as an observer moves farther away from the barrier. The sound levels cannot be reduced below these background levels, although in some cases, the noise very near the barrier may be slightly lower, because this area is farther away from nearby sources that contribute to the background. Only the CNM considers the effect of the background levels during the computer predictions. This results in unreal insertion loss being predicted in areas of high background noise levels from nonhighway sources by the other models and also leads to predictions of the shadow zone extending farther into the community than it really occurs.

Now consider Figure 1*b*. This figure is more representative of what a typical shadow zone would be, accounting for diffraction, scattering, refraction, and background levels. Scattering and diffraction make the top of the zone irregular or fuzzy. Ground effects make the shadow zone less dark near the ground and away from the barrier. Background noise limits the distance the shadow zone extends behind the barrier. Because the barrier design models do not account for background noise, it must be considered independently, outside of the model. Relying just on reported attenuations from the models may not lead to the expected sound levels after barrier installation due to these unaccounted effects. It may also lead to the conclusion that there are more benefited receiver locations than actually occur.

But it should be noted that the model prediction of the shadow zone is based on the insertion loss. The idea of shadow zones is often confused with insertion loss. For the insertion loss, as the receiver location is raised further from the ground surface, the ground effects, or attenuation, become less. Additionally, as an observer gets further away from the barrier, on the receiver side, the insertion loss is also reduced but ground effects and reductions due to geometric spreading increase. Other parameters may also affect the darkness of the shadow zone. Thus, these other parameters influence the prediction accuracy behind the barrier as well as influencing the barrier attenuation (diffraction) calculations.

Analysis of the measured data showed that because of lost ground effects with the barrier, greater insertion losses occurred at heights above 1.5 m than at 1.5 m. The TNM predicted this effect, whereas the other models did not. The other models neglect ground effects when the barrier is greater than 3.05 m. Thus, the TNM is predicting both barrier attenuation and ground effects at the critical 1.5-m height, whereas the other models are only reporting barrier attenuation. The authors consider this to be a major reason that shorter barriers may be predicted with the TNM and one reason a greater insertion loss is predicted than with the other models.

Remembering the shadow zone shape, the reader is asked to consider how it compares to an insertion loss contour plot. Figure 2 is used to illustrate this idea. The insertion loss near the ground is less than above the ground, due to the loss of ground effects when the barrier is used. This important effect was measured and predicted by the TNM. This has led the authors to change the CNM to include the ground effect algorithms used in the TNM based on the Embleton, Piercy, and Daigle methodology (*12*).

It should also be remembered that the insertion loss curves can be significantly affected by the background levels. Good practice would be to model all nearby roadways that have an effect on the local

TABLE 5 Propagation Losses Statistical Results Summary (Base Units, L_{Aeq})

Model	MIN	MAX	Gross Error	Variance	Root MSSE	Avg. Bias	Frac. Bias
TNM	**-2.3**	4.3	**1.9**	3.6	**2.3**	1.2	0.1
STAMINA2.0	-6.1	0.7	3.0	2.8	3.3	-2.9	-0.2
STAMINA2.1	-6.0	**0.4**	3.0	**2.5**	3.3	-2.9	-0.2
UCF CNM	-4.1	2.5	2.5	8.5	3.3	**0.9**	0.1

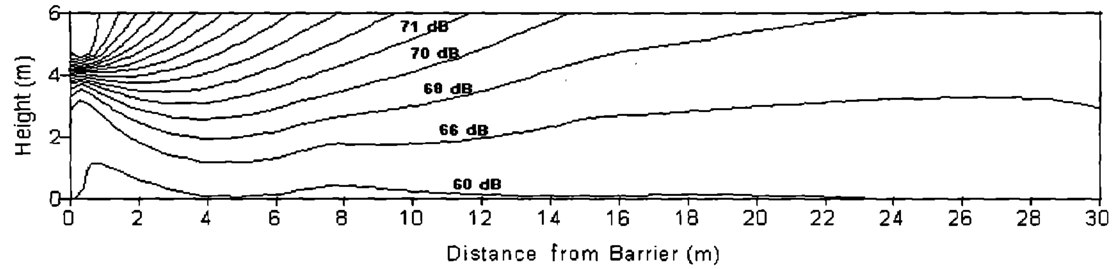

FIGURE 3 Absolute levels behind barrier, Site B, River Road, Jacksonville (Duval County).

determination was made if each microphone position was still in the shadow zone. For this determination, the insertion losses using the ANSI indirect method were used. Use of the insertion losses also allowed the determination of how far the measured sound levels were below the nonbarrier case in dB (A) [e.g., 5 dB (A) or 10 dB (A) of benefit]. This task was made more difficult because of the smaller insertion losses predicted near the ground due to lost ground effects.

Another problem also occurred. In most cases, except in the case of shorter barriers, all 1.5-m-high microphone locations were in the benefited region. In these cases, the predicted values from the TNM were adjusted at the last tower to match the measured sound levels. The predicted fall-off rate from the TNM was then used to predict the position or distance where the benefit dissipated, or reached the background levels.'This benefited region as discussed above was then plotted (Figure 4). In the figure, the 5 dB (A) benefited area and 10 dB (A) benefited area are displayed. The reader should note the large difference from this shape and what is thought to be a shadow zone.

In some cases, unusual shapes occurred. At one location, noise from a nearby roadway on the home side of the barrier caused the benefited region to be small as sound levels close to the barrier quickly reached the background level. At other locations, shielding from other obstructions than the barrier reduced the benefited region that was caused by the barrier alone. These plots effectively showed the limits of the benefited area created by the barriers. It is very obvious that the distance behind the barrier to which the benefited region extends is a function of the barrier height, ground effects, and background noise levels. Table 6 shows the background level, effective barrier height, and extent of the 5 dB (A) behind the barrier. Of interest is that without these considerations, the benefits are predicted to extend farther behind the barrier. This would lead to more dwellings being predicted to receive benefits than would really occur and also lead to underprediction of noise levels away from the barrier.

CONCLUSIONS

From the results presented, it can be concluded that the propagation algorithms in the TNM are significantly better. Statistical testing and comparison to measured differences have proven this. However, it cannot be stated that absolute levels were better predicted in these tests in Florida. Although the range of prediction was closer for the TNM, statistical testing proved STAMINA2.1 to provide the best results. Further consideration was required about why these results occurred. Because the propagation algorithms for the TNM did perform better, and the REMELs were slightly closer, it can be concluded that other problems, possibly offsetting errors, must exist in the STAMINA models. Although accuracy is the goal of modeling, this result from the STAMINA models does not appear to be a good foundation to continue to build on.

It was also advantageous to compare the predicted insertion loss from the TNM with measured values and with results predicted from STAMINA2.1. This testing showed that in most cases, but not always, the TNM predicted greater insertion losses. This would tend to imply that shorter barriers may be designed using the TNM rather than using STAMINA.

Considerable work was also done on understanding the benefited region and the reason for this greater insertion loss prediction from the TNM as compared with the other models tested. It should be remembered that the shadow zone and insertion loss, though dependent, are not the same. The analysis showed that the TNM was predicting the ground effects correctly behind the barrier and that the other models neglected this important consideration. Thus, the TNM methodology for the insertion loss trends near the ground and at the 1.5-m locations is more theoretically correct than for the other models. This is considered by the researchers to be the key parameter in why greater insertion losses are predicted by the TNM compared with those by the other models.

Also, with the exception of the CNM, the other models do not consider background levels, and that is a constraint to how far the benefited region can extend behind the barrier. Work was done to determine the extent of the benefited regions. These regions are dependent on barrier heights, ground effects, and background levels, as well as on barrier attenuation. Neglect of background levels in the barrier design models could lead to underprediction of noise levels away from the barrier and determination of more dwelling units receiving more abatement than would really occur.

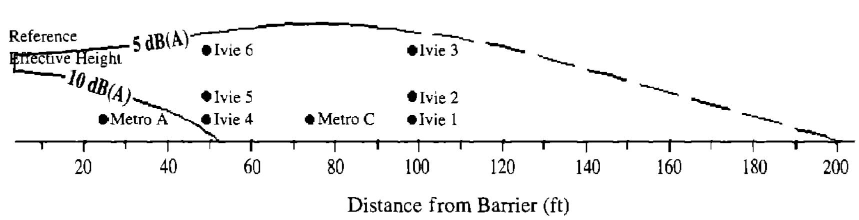

FIGURE 4 Typical shadow zone plot (20 ft = 6.1 m).

Application of the Boundary Element Method to Prediction of Highway Noise Barrier Performance

Sanghoon Suh, Luc Mongeau, and J. Stuart Bolton

The boundary element method has proven to be an important tool for the computational solution of many engineering problems. A commercial boundary element code was applied to traffic noise barrier analysis. First, it is shown that boundary element models may be used to quantify the accuracy of existing, approximate barrier models, for example, diffraction-based models. Diffraction-based models have been widely applied in noise control engineering applications owing to their relative ease of use. Recently, it was suggested that multipath diffraction components should be summed on a phase-coherent basis instead of on an energy basis. Here the accuracy of a phase-coherent diffraction model has been verified against the boundary element solution, showing limitations of the diffraction model. Second, the boundary element method was used to calculate a new barrier performance metric. In the past, the insertion loss has been considered the most important measure of noise barrier performance. However, insertion loss is normally defined at a particular receiver point in the shadow zone, and its value may vary significantly from point to point. The propagating sound power calculated on a recovery plane in the barrier shadow zone provides a more effective performance measure than does insertion loss when comparing the performance of different barrier designs.

Much research has been focused on the understanding of diffraction around barriers, with the intention of developing effective barrier designs. Many theoretical barrier diffraction methods are in fact semi-empirical and are based on the application of ray-tracing and geometrical acoustics procedures. The most influential early studies were those of Maekawa (*1*) and Kurze and Anderson (*2*), who developed techniques for predicting the insertion loss of reflecting, sharp-edged barriers in terms of the Fresnel number. Lam (*3*) improved on Maekawa's method by summing the complex pressures instead of the energies traveling along each of the diffraction paths around finite length barriers. Fyfe (*4*) subsequently extended Lam's research by using the Kurze and Anderson formulation as well as Pierce's (*5*) in combination with Lam's summation procedure with successful results. In addition, Pierce has formulated an approximate solution to the wave equation for single-edge diffraction by a semi-infinite wedge, which is believed to be more rigorous than the Kurze and Anderson formulation. However, Pierce's solution involves the computation of Airy functions and Fresnel integral functions, which may be difficult to use in engineering applications.

In one component of the work described in this paper, the Kurze and Anderson (*2*) formulation was used in combination with Lam's formulation (*3*) to create a diffraction model that can be used to predict the insertion loss of both infinitely long barriers and finite length barriers placed on rigid ground surfaces. The accuracy of this model was then verified by comparing its predictions to exact results calculated numerically by using the boundary element method.

The use of the boundary element method to make insertion loss predictions for barriers that have more complicated shapes than simple linear barriers has been investigated by Hayek (*6*) and Hothersall (*7*). It will be shown here that the boundary element method has important advantages over methods based on a geometrical diffraction approach, that is, diffraction-based models. The main advantage of the boundary element method is its ability to handle arbitrarily shaped barriers. It also has the advantage of being more accurate than approximate, diffraction–based theories in that a solution of the governing wave equation to any required accuracy can be obtained. On the other hand, the disadvantage of the boundary element method is that it may require large computation times and storage, especially for barrier designs that vary along their length as well as in their cross-section. Nonetheless, owing to the increasing power of computer systems, it is now becoming feasible to use the boundary element method in realistic barrier design applications.

The object of the work described in this paper was thus first to compare diffraction-based, ray-tracing models and boundary element models (BEMs) with particular attention paid to the accuracy of the diffraction models near the boundary of the geometrical shadow zone.

Second, the issue of barrier performance metrics was considered. In practice, barrier performance has usually been quantified by using the insertion loss—that is, the sound pressure level behind the barrier relative to the sound pressure level at the same location without the barrier in place. However, the insertion loss should be used with caution when comparisons are made between different barrier shapes, because it quantifies the barrier performance at only a single point within the shadow zone. It will be shown here that the insertion loss varies significantly from point to point within the barrier shadow zone and that this variation makes it difficult to judge the relative performance of candidate barrier designs. It will be suggested instead that the sound power propagating through the complete shadow zone behind a barrier is a more useful metric for quantifying and comparing barrier performance. The application of this performance metric to the identification of an optimal barrier design will be demonstrated.

THEORY OF DIFFRACTION-BASED METHODS

Two-Dimensional Analysis

Consider the situation shown in Figure 1, in which a source and receiver are separated by a semi-infinite barrier. The pressure arriving at the receiver along the ith path, p_i, can be represented as

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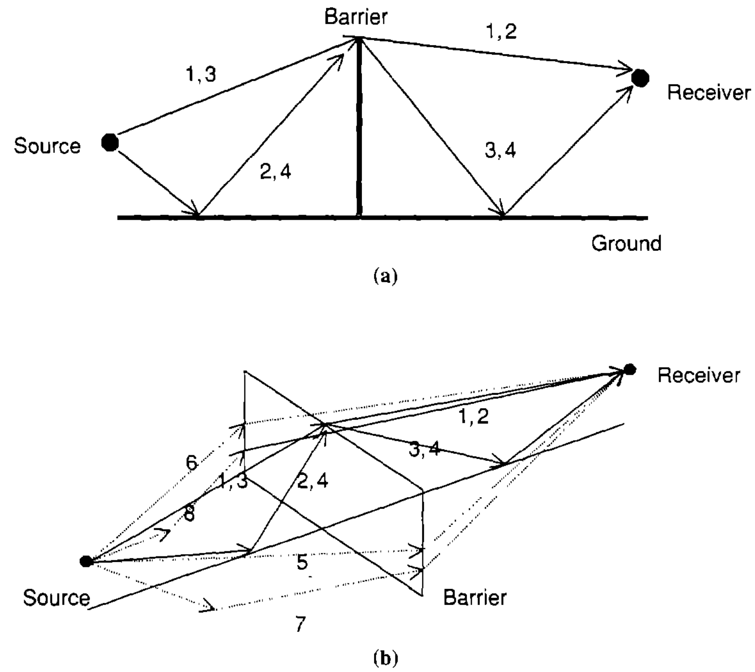

FIGURE 2 Barrier diffraction paths: (a) finite height, infinite length; (b) finite height, finite length.

istics of noise barrier performance—in particular, that a barrier is not effective at low frequencies.

The insertion loss for a 3-m-tall barrier placed on a hard ground surface is shown in Figure 3*b*. The source and receiver geometry was the same as for the case illustrated in Figure 3*a*, and the calculation was first performed using the diffraction model discussed earlier. In the finite-height barrier case, the additional ground reflection paths result in interference between the various diffracted sound rays with the result that a number of peaks and dips appear in the insertion loss. Thus, one result of ground reflection is to cause the performance of a barrier to display a strong dependence on frequency.

The boundary element code SYSNOISE (*8*) was then used to calculate an exact, two-dimensional, wave-based solution for the same problem. SYSNOISE itself does not feature a preprocessor for creating discretized models, but it offers interfaces to a variety of preprocessors. MSC Patran (*9*) was used to generate the various models used here. In the two-dimensional case, a cylindrical line source was assumed to generate the sound field. In the case of a barrier placed on a hard surface, it is still only necessary to discretize the barrier surface, because the presence of a uniform reflecting plane can be accounted for automatically in the boundary element calculations.

Note that a typical boundary element analysis is performed in two steps. First, the Green's function appropriate for the particular sound source and model geometry is computed. After that calculation is performed, the sound field at arbitrary receiver points can be calculated in a postprocessing stage. It is the first step of this procedure that requires the majority of the computation time. To reproduce the diffraction-based calculation of Figure 3*b*, 300 surface elements were used to represent the barrier, and the maximum analysis frequency (based on the requirement that there be at least six elements per wavelength at the highest frequency of interest) was 5667 Hz. To create the results presented here, the analysis was performed from 10 Hz to 2000 Hz in steps of 10 Hz. In the present case, the central processing unit time required for first step of the boundary element calculation was 431 s on an IBM RS-6000 workstation.

A comparison of the insertion losses calculated by using both the diffraction model and the BEM is shown in Figure 3*b* for the receiver point (20, 1.5), that is, for a point 20 m behind the barrier and 1.5 m above the ground. It can be seen that there is generally good agreement between the two models except in the vicinity of the insertion loss peaks, which are systemically underestimated by the diffraction model, particularly at low frequencies. The latter behavior is characteristic of diffraction-based model.

It was noted earlier that one disadvantage of diffraction-based models is their inability to handle receiver points near the line of sight, that is, close to the shadow boundary. The results presented in Figure 4*a*, 4*b*, and 4*c* illustrate that point: the model geometry was the same in this case as in the case illustrated in Figure 3*b*, except that the receiver was moved progressively closer to the shadow boundary. The results shown in Figure 4 demonstrate that the accuracy of the diffraction-based predictions does indeed deteriorate as the receiver point approaches the shadow boundary. Note again that the diffraction-model error is greater in the lower frequency range than in the higher frequency region.

Three-Dimensional Model

In this case, we begin by considering a simple comparison of two- and three-dimensional diffraction models before proceeding to validate the three-dimensional diffraction model by comparison with the boundary element solution. The insertion loss for a 20-m-long barrier is shown in Figure 5, where it is compared with an equivalent result for an infinitely long barrier. It can be seen in that figure that the insertion loss of a finite-length barrier is reduced compared with that of an infinitely long barrier as a result of diffraction around the barrier edges. In this case, the sound source was positioned 5 m in front of the barrier and 0.5 m high, halfway along the barrier's length. Note also that in the three-dimensional case a point source was assumed. The height of the barrier was 3 m and the receiver was placed 20 m behind the barrier at a height of 1.5 m midway along the barrier's length.

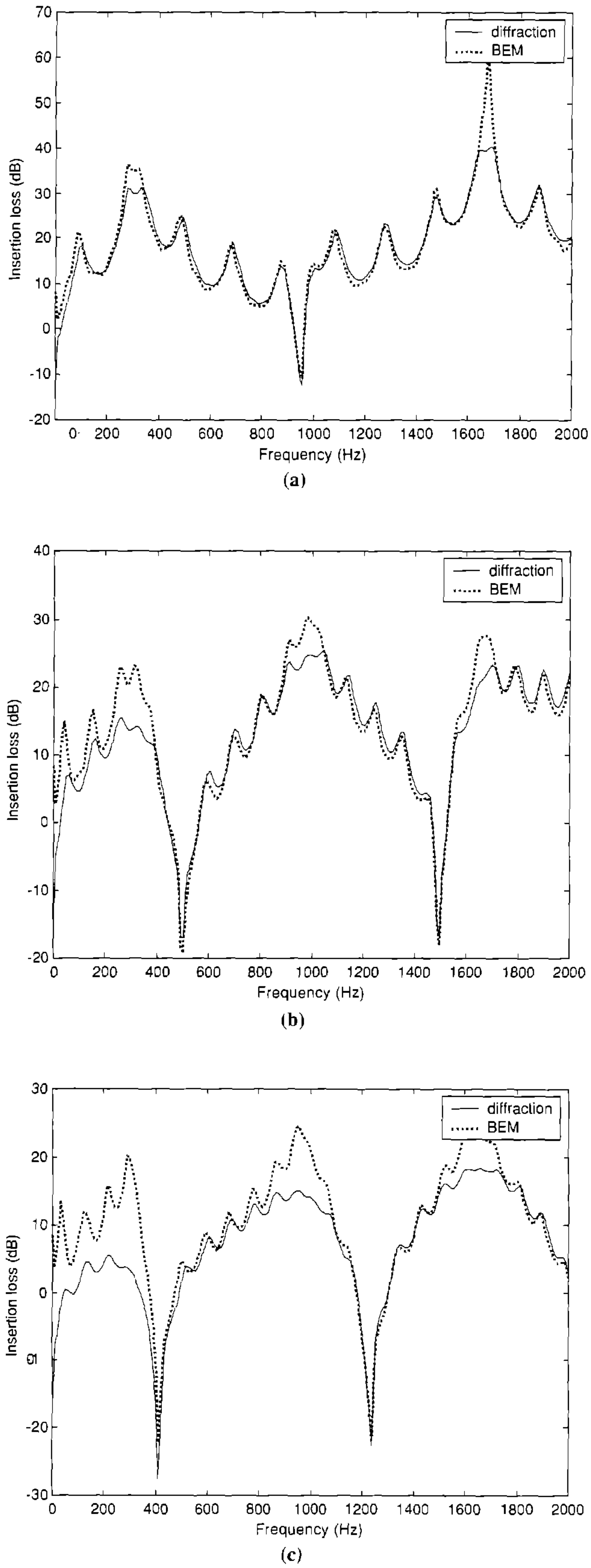

FIGURE 4 Comparison of insertion loss calculated by using the diffraction-based model and boundary element model (BEM): (*a*) receiver point (6, 2); (*b*) receiver point (6, 4); (*c*) receiver point (6, 5).

To conduct a numerical analysis of a finite-length barrier, a three-dimensional BEM must be created. The number of surface elements in a three-dimensional BEM can be quite large even for a moderate maximum frequency, because it is necessary to discretize the barrier surface over its complete length. To make a computation practical in the present instance, the size of the barrier was reduced to 1.5 m high by 4.0 m in length. The number of boundary elements was 2,400 in this case and the maximum analysis frequency was 1100 Hz. The point sound source was assumed to be located 5 m in front of the barrier, 0.5 m high and midway along the barrier's length. The receiver was located 20 m behind the barrier at a height of 1.5 m and midway along the barrier's length. The analysis was performed from 10 Hz to 1000 Hz in steps of 10 Hz. In this instance, the Green's function calculation took 29,353 s on the IBM RS-6000, considerably longer than for the two-dimensional case.

The comparison of the insertion loss results calculated using the diffraction and BEMs is shown in Figure 6. Most significantly, it can be seen that the diffraction model again fails at low frequencies.

The results presented in this section have shown that it is possible to establish the accuracy and performance limits of the two- and three-dimensional, diffraction-based, noise barrier models of the type that are widely used in practice. It has also been found feasible from a computational point of view to use a two-dimensional BEM to predict the performance of infinitely long barriers. The same approach may be used to model finite-length barriers. But currently, the computation time required for three-dimensional, finite-length barrier models is relatively lengthy. It is anticipated that the latter point will become less of an issue as computer speeds increase.

NOISE BARRIER PERFORMANCE MEASURE

Relationship Between Receiver Location and Insertion Loss

The insertion loss calculated at particular receiver points is the usual measure of barrier performance, as in the cases discussed in the previous section, for example. However, as shown in Figure 7*a*, the insertion loss varies significantly at different positions within the shadow zone. In this two-dimensional case (calculated using the two-dimensional diffraction model given earlier), the barrier was 3-m tall, and the sound source was located 5 m in front of the barrier and 0.5 m high; the receiver point was moved in a sequence of steps from 5 to 25 m behind the barrier at a constant height of 1.5 m above the ground. It can be seen that at short ranges there is constructive interference between the various diffracted sound rays with the result that the insertion loss can be negative—that is, the barrier actually amplifies the sound level in some frequency ranges. For the receiver point at 5 m, the insertion loss is negative in the frequency range 1000 Hz to 1250 Hz, whereas the insertion loss is negative in the frequency range 1600 Hz to 1850 Hz when the receiver was moved to 10 m behind the barrier. This behavior reduces progressively as the receiver point is moved farther from the barrier. It can be concluded from these results that there is a very significant variation of insertion loss with distance behind a barrier.

The variation of insertion loss when the receiver was moved vertically at a constant horizontal distance from the barrier is shown in Figure 7*b* (again calculated using the diffraction-based model). In this case, all the receiver points were 20 m behind the barrier at the different heights shown in the figure, whereas all other parameters were the same as in the previous example. It can be seen that the insertion loss varies significantly with receiver height and generally

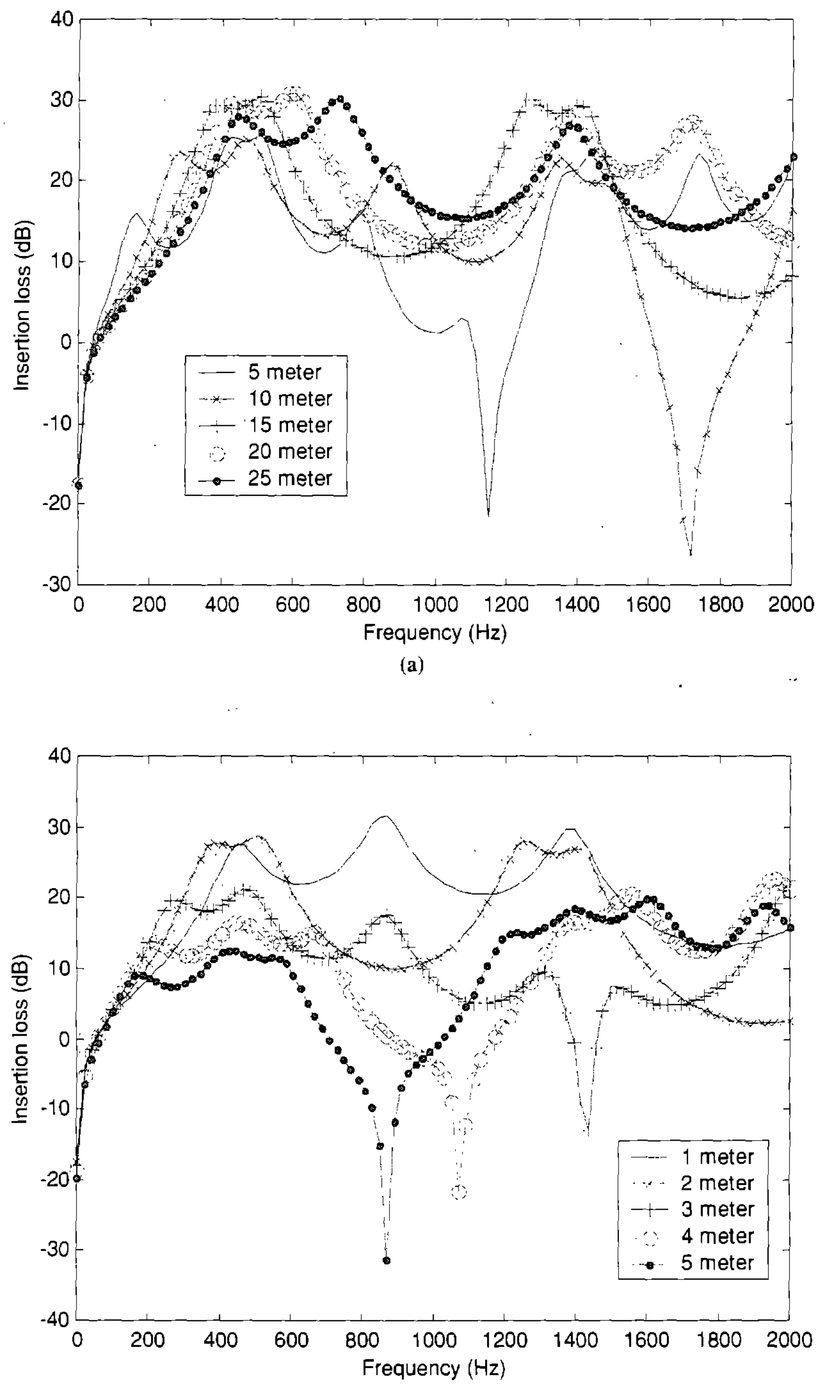

FIGURE 7 Comparison of insertion losses for different receiver locations: (*a*) (5, 1.5), (10, 1.5), (15, 1.5), (20, 1.5), and (25, 1.5); (*b*) (20, 1), (20, 2), (20, 3), (20, 4), and (20, 5).

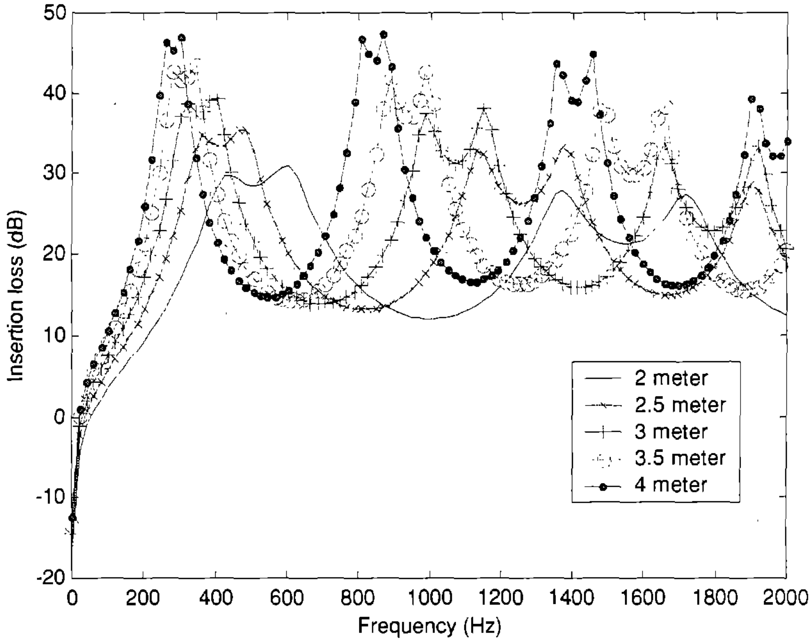

FIGURE 10 Comparison of insertion losses for barriers of different heights.

rier height on the insertion loss, two-dimensional calculations were performed for a case in which the heights and horizontal positions of both source and receiver were fixed while the barrier height was varied. The sound source was located 5 m in front of the barrier at a height of 0.5 m, and the receiver was placed 20 m behind the barrier at a height of 1.5 m. The barrier height was then increased from 2 to 4 m in steps of 0.5 m. The diffraction-based model given earlier in this paper was used to obtain the results presented in Figure 10.

The results given in Figure 10 illustrate that the insertion loss generally increases with barrier height. However, because the cost of building a noise barrier usually depends on its height, it is of interest to keep the barrier height as small as possible while maintaining a given level of noise control performance. It has been suggested that barrier insertion loss may be improved at a given barrier height by shaping the top of the barrier [for example, see Hothersall et al. (*10*)]. That idea is considered next.

Cross-Sectional Shape of Barrier Top

A two-dimensional boundary element procedure was used here to evaluate the performance of barriers having different cross-sections at their top. It was necessary to use a BEM for this analysis, because diffraction-based models can only deal easily with straightedge geometries. The height of all the barriers considered in these cases was 3 m, but the top of the barrier was given different horizontal widths, that is, the barrier was T-shaped. The cross-sections of the particular barriers considered here are shown in Figure 11. The sound source was placed 5 m in front of the barrier at a height of 0.5 m, and the receiver was located 20 m behind the barrier at a height of 1.5 m. The insertion losses of the T-shaped barriers having top widths of 10, 20, 40, and 80 cm are shown in Figure 12*a*. Results have also been calculated for a straight barrier for the purpose of comparison.

First note that it can be seen in Figure 12*a* that the insertion losses of all the various barriers are similar in the low-frequency region. Significant differences begin to emerge only above 3000 Hz. From this presentation, however, it is not apparent which, if any, of the T-shaped barriers gives better overall performance than the straight barrier. This difficulty arises because the sound field at only one receiver point was considered in the calculation of the insertion loss. Also, it has been shown in previous sections that the insertion loss varies significantly with location in the shadow zone and that the spatial variation of insertion loss in the shadow zone is different for each different barrier.

The sound power crossing a recovery plane located in the shadow zone 16 m behind the barrier is shown in Figure 12*b*. It can be seen that the interbarrier variability is apparently reduced when the shadow zone sound power is considered. To make clear the effectiveness of the various barriers in comparison to the linear barrier, the sound power propagating behind each T-shaped barrier was subtracted from the sound power propagating behind the straight barrier. Thus, the better the barrier performance in comparison with a linear barrier of the same height, the more positive is the result. The latter results are given in Figure 12*c*, and they show that in fact the T-shaped barrier having a 20-cm-wide top was the most effective among the four different T-shaped configurations tested, because it yields better performance than does the straight barrier at nearly all frequencies up to 5 kHz. In contrast, for all the other barriers, there are frequency ranges over

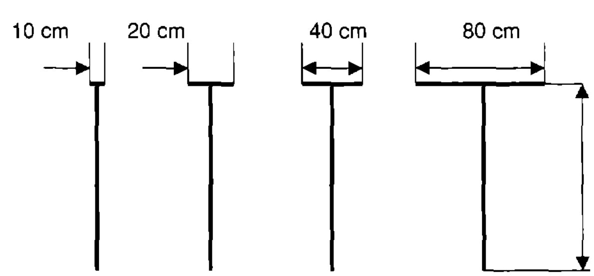

FIGURE 11 Cross-sectional view of various T-shaped barriers.

Transverse-Tined and Longitudinal Diamond-Ground Texturing for Newly Constructed Concrete Pavement
A Comparison

Paul L. Burgé, Keith Travis, and Zoltan Rado

The purpose of this study is to provide a comparison of longitudinal diamond-ground and transverse-tined pavement surface texturing for newly constructed portland cement concrete pavement (PCCP). The study area is located along a test section of I-190 in Buffalo, New York. The two PCCP surface treatment types under evaluation are compared based on safety, noise, construction cost, service life, rideability, handling, and maintenance requirements. The initial evaluation is documented, as is the analysis of follow-up noise and skid resistance measurements conducted approximately 1 year later. Analysis of the initial testing indicates that the relative skid resistance of the experimental longitudinal diamond-ground surface is as good or better than that of the transverse-tined surface. The results of the noise analysis indicate that the longitudinal diamond-ground surface is 2 to 5 dB quieter depending primarily on the traffic vehicle mix. Noise and skid resistance measurements conducted 1 year later showed little change. Although less construction time was required for the transverse-tined pavement compared with that for the diamond-ground pavement, the actual cost difference is not quantifiable. However, a higher initial cost for longitudinal diamond grinding would likely be partially offset by an extended service life.

Surface texturing of concrete pavement is required on projects funded by FHWA to reduce skidding under wet pavement conditions. Portland cement concrete pavement (PCCP) surfaces are often finished with a transverse-tined texture during construction to increase skid resistance. Alternate pavement surface treatments are occasionally considered in an effort to reduce the tire–pavement noise associated with the traditional finish. However, a compromise in the safety or a reduction in the effective service life along with significant added construction costs would bring undesirable side effects resulting from efforts to achieve a reduction in traffic-generated noise levels.

As part of a New York State Thruway Authority (NYSTA) highway reconstruction contract, a new PCCP surface texturing technique was implemented along portions of the Niagara Section of the NYS Thruway, Interstate 190 (I-190). The experimental surface treatment (longitudinal diamond-ground texturing) was implemented adjacent to noise-sensitive areas in lieu of the conventional transverse-tined concrete surface texturing method currently approved by FHWA. The purpose of this study is to provide a comparison of key performance characteristics between longitudinal diamond-ground and transverse-tined pavement surface texturing for newly constructed PCCP.

The test section of the highway included newly constructed segments of both traditional transversely tined PCCP and the experimental longitudinal diamond-ground PCCP. Sample sections of both pavement types were included on both northbound and southbound lanes. The test section of northbound pavement was opened to traffic in December 1999. The test section of southbound pavement was opened to traffic in December 1998.

APPROACH

The two PCCP surface treatment types evaluated in this study are compared based on safety, noise, construction cost, service life, rideability, handling, and maintenance requirements. Comparisons are made on a section of highway of the same construction (other than surface treatment) and exposed to the same traffic and weather conditions.

Skid testing and accident reports are used to evaluate safety characteristics. Noise measurements and analytical modeling are used to compare the traffic-generated noise levels. The unit price bid by the awarded construction contractor is used to compare relative construction costs. User surveys are used to obtain feedback from highway maintenance personnel, state police, and the general traveling public to assess differences in rideability, handling, and maintenance requirements. Each of the aforementioned characteristics will be monitored over a period of 5 years to assess the service life of each PCCP surface treatment.

This paper reports the results and analysis of construction cost data and the initial set of noise and skid resistance measurements plus follow-up measurements conducted approximately 1 year later. Additional follow-up noise and skid-resistance measurements will be conducted annually through 2005, to continue documenting changes in pavement properties.

MATERIALS AND CONSTRUCTION DETAILS

Construction practices and materials used for the pavement test sections were kept as consistent as possible between the two pavement types, except for the actual surface treatments, detailed as follows.

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available for both pavement types. Therefore, the single vehicle pass-by measurements were conducted at a distance of 7.5 m (25 ft) and adjusted to the 15-m (50-ft) reference distance using the measured drop-off correction.

The results of the single vehicle pass-by measurements (adjusted for the reference distance) were graphed to show individual vehicle data points. Linear regressions representing each pavement surface type were calculated for automobile, medium truck, and heavy truck types. An example of the data and regression curves for automobiles (including light trucks) is shown in Figure 1. Similar graphs were generated for medium trucks and heavy trucks.

Drop-Off Noise Measurements

The primary single vehicle measurement site, near the interface of the two pavement types, did not allow for the required 15-m wayside measurement position due to an existing embankment. A secondary measurement location was selected to measure the single vehicle drop-off correction. An average drop-off correction value of 6.2 dB was measured for all vehicle types.

Aggregate Traffic Measurements

Long-term (24-h) aggregate traffic noise measurements were taken to determine the loudest hour of the day for the study area. Short-term (1-h) aggregate traffic noise measurements were collected during the loudest hour of the day concurrently with classified traffic counts to identify time-averaged noise level for both pavement types and associated traffic mix.

Traffic Noise Model Analysis

The FHWA TNM is a Windows computer–based analytical model that predicts traffic generated noise levels. The program predicts hourly average noise levels in A-weighted decibels (dBA) based on traffic volumes and mix, roadway and landscape topography, and other factors. The program uses REMELs for a variety of vehicle types (automobiles, medium trucks, heavy trucks, buses and motorcycles) for a number of standard pavement types, including standard PCCP, dense grade asphalt, open grade asphalt, and an average of all pavement types. The program also provides for the input of user-defined REMELs for special vehicle types.

TNM User-Defined Vehicles Parameters

With the use of single vehicle pass-by measurement data for each pavement type, parameters required to specify user-defined vehicles in FHWA's TNM were developed for each of the three primary vehicle types (automobiles, medium trucks, heavy trucks). User-defined vehicle parameters were developed for both pavement types. Table 1 summarizes input parameters developed from the noise measurements, along with 95% confidence limits for the linear regression of each vehicle and pavement type.

The minimum level parameter specified in Table 1 is representative of low-speed vehicle noise, where the noise level is assumed to be dominated by engine and exhaust noise (independent of tire–pavement noise contributions). Because the data collected for this study are limited to vehicles traveling at highway speeds (80 to 140 km/h), the published TNM standard minimum levels for each of the three vehicle types are used. TNM runs using new REMEL parameters for the candidate pavement types were validated to within approximately 1 dB when compared with aggregate noise measurements.

TNM Vehicle Mix Scenarios

Four theoretical traffic mix scenarios were developed as a comparison parameter for pavement noise levels as follows:

1. Parkway: 100% automobiles and light trucks;
2. Light truck usage: 95% automobiles and light trucks, 5% medium and heavy trucks;
3. Moderate truck usage: 80% automobiles and light trucks, 20% medium and heavy trucks; and
4. Heavy truck usage: 60% automobiles and light trucks, 40% medium and heavy trucks.

TNM Predicted Noise Levels

Employing the user-defined vehicle parameters generated from the pavement specific pass-by data, as presented, TNM was used to pre-

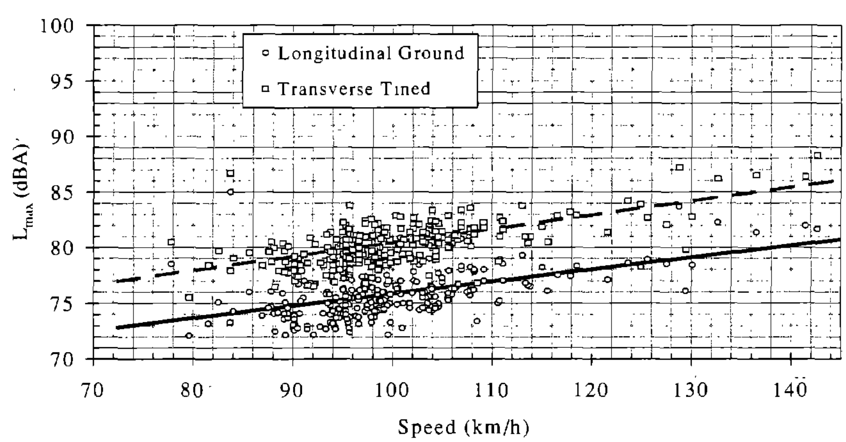

FIGURE 1 Single vehicle pass-by measurements for automobiles.

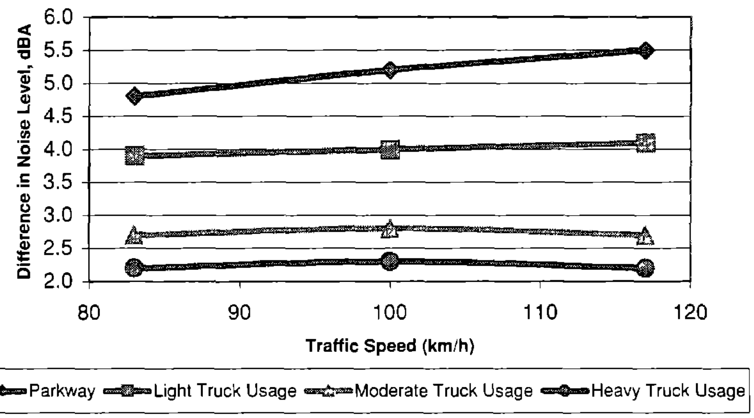

FIGURE 3 Relative difference in noise level as a function of vehicle speed (transverse tined minus longitudinal ground).

icant contribution for heavy and medium trucks at highway speeds. This suggests that higher percentages of heavy and medium trucks using the roadway would diminish the relative acoustical advantage of the longitudinally ground pavement. This conclusion is supported by the TNM-predicted noise levels, which indicate that the longitudinal ground pavement would be approximately 5.4 dBA quieter than the transverse-tined pavement the parkway scenario (100% automobiles) but only about 2.2 dBA quieter for the heavy truck usage scenario (Figure 4). A 2 dBA–difference in noise level is generally below the threshold of a perceptible difference to the average human ear.

The comparison of TNM-predicted noise levels also suggests that receiver distance and small line of sight obstructions (such as a Jersey barrier) play a lesser role in the relative noise levels of the two pavement types (Figure 2). The presence of a Jersey barrier reduced the relative benefit of the longitudinally ground pavement by less than 0.5 dBA. The influence of distance on the relative difference in noise levels of the two pavement types was 0.3 dBA or less. The influence of vehicle speed on relative noise level was generally less than 0.5 dBA depending on vehicle mix, over the range of typical highway speeds (Figure 3).

SKID TESTS AND MACROTEXTURE MEASUREMENTS

Skid resistance and macrotexture measurements were performed in April 2000 and June 2001. Tests were conducted on the longitudinal diamond-ground and transverse-tined PCCP surfaces in the north-

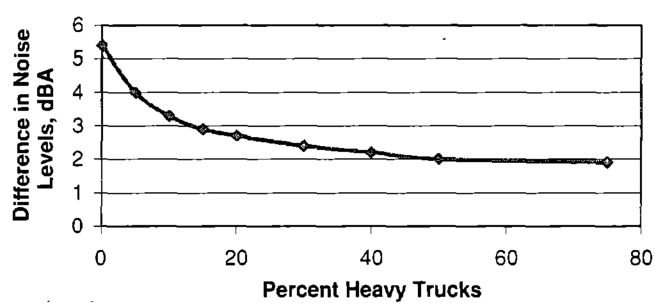

FIGURE 4 Relative difference in noise level as a function of heavy truck usage (transverse tined minus longitudinal ground).

bound lanes (constructed in 1999) and the southbound lanes (constructed in 1998). Tests were performed in both the driving lane and passing lane.

Skid resistance measurements were made at 67, 83, and 100 km/h (40, 50, and 60 mph) on each surface treatment with both blank and ribbed test tires. Skid resistance is defined as the retarding force generated by the interaction between a pavement and a tire under a locked-wheel condition (*6*). To ensure that measurements made at various times and places can be compared with each other, a standardized tire was used and a standard amount of water was applied to the dry pavement ahead of the tire. The details of the skid resistance test procedure are described in ASTM E 274 (*7*). The details of the blank and ribbed standard test tires are described in ASTM E 524 (*8*) and ASTM E 501 (*9*), respectively. A minimum of five measurements per test section were conducted and used to calculate an average for each test section. The results of the pavement skid test are reported in Table 3 as the skid number (SN).

The values reported in Table 3 are reasonable and are considered accurate in accordance with ASTM standards. The effect of speed is consistent and as expected (SN decreases when speed increases) for the average SN. The acceptable precision of SN units can be stated in the form of repeatability. ASTM E 274 suggests an acceptable standard deviation of 2 SN units.

The two different test tires were used to measure two different pavement surface characteristics. Tests performed using the blank (smooth) test tire represent the pavement's macrotexture, whereas measurements made with the ribbed test tire best represent the pavement's microtexture. In general, microtexture provides the frictional capability of dry pavement. Macrotexture provides the drainage capability at the tire–pavement interface and therefore how effective the microtexture will be when the pavement is wet.

Good microtexture is obtained by using suitable aggregate in the pavement surface. Fine aggregates containing a minimum of 25% siliceous sand, durable nonpolishing coarse aggregates a low water-to-cement ratio, adequate air content, adequate cement factor, and good curing practices are all necessary to obtain high-quality durable concrete (*10*).

To further investigate the pavement surface's macrotexture, mean texture depth (MTD) measurements were performed. This measurement involves spreading a known volume of glass spheres on a clean, dry pavement surface; measuring the area covered; and calculating the average depth between the bottom of the pavement surface voids and

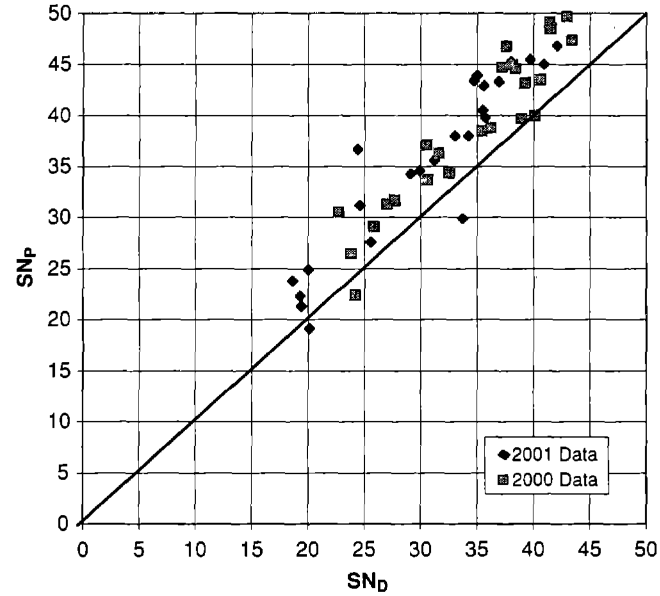

FIGURE 5 Skid resistance for driving lane versus passing lane. (SN_D = skid number driving lane; SN_p = skid number passing lane.)

deteriorates more quickly, so that after 1 year, longitudinal diamond-ground and transverse-tined macrotextures are more equal.

In summary, initial results show a greater loss of macrotexture (MTD and SN_B) for the experimental longitudinal diamond-ground surface than for the transverse-tined surface. However, the relative skid resistance of the experimental longitudinal diamond-ground surface tends to be higher than that of the transverse-tined surface using a blank tire (representative of the surface macrotexture-resistance to wet pavement accidents). There is no significant difference in the skid resistance measured with the ribbed tire (representative of the surface microtexture), as would be expected since both pavements were constructed using the same mix design.

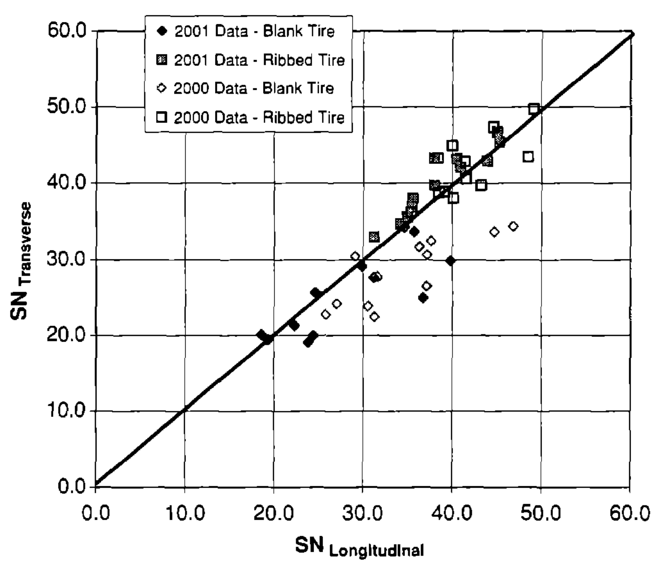

FIGURE 6 Skid resistance for longitudinal ground versus transverse-tined PCCP.

DISCUSSION OF RELATIVE SERVICE LIFE

The pavement skid resistance is expected to change over a period of several years. Comparing the data for the experimental longitudinal diamond-ground surface constructed in 1998 with that constructed in 1999 yields no significant difference in mean SN value (Table 3). Comparing the data for the transverse-tined surface constructed in 1998 with that constructed in 1999 yields a small difference in mean SN. The 2001 data show even less difference in mean SN between the different construction years for the transverse-tined surface. This would indicate that the small difference in skid resistance between the northbound surface and the southbound surface is diminishing.

Another consideration is the life-cycle cost. Similar studies (*14, 15*) have shown a long-term benefit from diamond grinding. The studies speculate that the benefit is realized from reduced pavement joint fatigue that results from the smooth surface created by diamond grinding. Profilograph readouts from this project show that the diamond grinding creates a significantly smoother profile, so the diamond grinding process may show a long-term (20 years and more) benefit due to the increased service life.

Note that these data were collected from 177 rehabilitated highway sections in 26 states throughout the country. To date, no known data are available on the longevity of newly constructed diamond-ground pavements, which may differ from the rehabilitated highways in that the concrete is harder due to the additional curing time.

FUTURE RESEARCH, YEAR 2001

Pavement noise and skid resistance testing is to be continued annually over the next several years, to further document changes in these parameters over time. The data should be measured at the same time of the year (i.e., spring) to avoid changes in measured values caused by short-term and long-term seasonal variations. Traffic volumes and accident data will also be collected. Interviews with various highway users such as state troopers, maintenance personnel, and others will be conducted to determine if there are noticeable differences in maintenance requirements, vehicle operation, or rider comfort while traveling over the different pavement surfaces.

CONCLUSIONS

Construction Time and Cost

The longitudinal diamond-ground pavement will require more construction time and will cost more than transverse tining will. However, a higher initial cost for longitudinal diamond grinding would likely be partially offset by an extended service life.

Pavement Noise

The longitudinally diamond-ground pavement was shown to be 2 to 5 dBA quieter than the transverse-tined pavement, depending mostly on the percentage of heavy trucks in the vehicle mix. The longitudinally ground pavement was approximately 3 to 4 dBA quieter for typical highway traffic mix and speed. Aggregate traffic noise measurements made after approximately 1 year showed virtually no difference in relative or absolute noise levels.

Defining Reasonable and Feasible Traffic Noise Abatement

Consideration of Quantitative Approach

Win Lindeman

Where did all of this business about reasonable and feasible traffic noise abatement begin, and how can it best be incorporated into today's environmental impact assessment process? These questions prompted a third: How can the decision-making process be improved when it comes to determining when traffic noise abatement is reasonable and feasible? Historically, the consideration of reasonable and feasible traffic noise abatement can be traced to FHWA's directives issued in 1973. Following more than two decades of application by state highway agencies, FHWA issued a report in 1992 that questioned what criteria should be used to determine reasonable and feasible traffic noise abatement. This report prompted the Florida Department of Transportation (FDOT) to assess its process related to reasonable and feasible abatement. After nearly a decade of adjustment and tweaking of the current process, FDOT has developed an alternative methodology. This quantitative method could be used to assess noise abatement reasonableness and feasibility and help to remove the appearance that subjective abatement decisions are being made. The quantitative methodology that FDOT developed would reduce the appearance of subjectivity by applying a series of quantifiable criteria that use numeric values to produce a summed value. When the summed value is compared with an established range, it would indicate whether noise abatement is reasonable and feasible for the given situation.

Historically, assessing traffic noise impacts has been a part of FHWA's procedure since January 14, 1969. At that time, FHWA issued Policy and Procedure Memorandum (PPM) 20-8. The purpose of PPM 20-8 was to ensure that highway locations and designs were "consistent with Federal, State, and local goals and objectives" (*1*). In Paragraph 4, FHWA defined environmental effects, which included noise. This set the stage for FHWA and Florida Department of Transportation (FDOT) to require assessment of traffic noise impacts as part of all appropriate highway construction projects.

By February 8, 1973, FHWA had issued PPM 90-2, *Noise Standards and Procedures*. In Appendix B, Paragraph 2 (b) (2), the state highway agency (SHA) was required to "thoroughly consider all feasible measures that might be taken to correct or improve the noise condition" (*2*). Further in Paragraph 2 (b) (3), there is a requirement to assess "noise abatement measures considered against the benefits which can be achieved as well as against other conflicting values such as economic reasonableness . . ." (*2*).

Thus the stage was set for SHAs to identify when traffic noise abatement was to be considered feasible and reasonable. By May 4, 1973, FHWA issued the notice *Interpretation of PPM 90-2*, in which the question of reasonable and feasible abatement measures was raised (*3*). As can be readily seen, questions and interpretations of reasonable and feasible traffic noise abatement have been around for quite some time.

By May 14, 1976, FHWA transmitted to the SHAs the Federal-Aid Highway Program Manual (FHPM) Volume 7, Chapter 7, Section 3, *Procedures for Abatement of Highway Traffic Noise and Construction Noise*. In Paragraph 7 (e) (1), FHWA states that the SHA shall identify "noise abatement measures which are reasonable and feasible and which are likely to be incorporated in the project" (*4*). This concept continues today and can be found in Section 772.11 (e) (1) of the latest edition of 23 Code of Federal Regulations, Part 772, *Procedures for Abatement of Highway Traffic Noise and Construction Noise* (*5*).

However, one is still faced with the ultimate question: When is traffic noise abatement considered to be reasonable and feasible? FHWA attempted to give some guidance to this question in 1982 with the issuance of a memorandum by Jerry Reagan, titled "A National Field Review of the Highway Traffic Noise Impact Identification and Mitigation Decisionmaking Process." In the report, that author attempted to define feasibility and reasonableness of traffic noise abatement. He noted that feasibility "deals more with the engineering considerations, i.e., can the barrier be built, can the noise reduction be achieved, etc. Reasonableness is a more subjective criterion than feasibility, that is, property owner's input, cost of noise reduction, impact of projects, people's perception of the noise reduction. Reasonableness implies that common sense was applied in arriving at a decision" (*6*). This was FHWA's first significant attempt to define the many elements of feasibility and reasonableness associated with traffic noise abatement and imparts this guidance to the SHAs.

A June 1989 Field Review Report from FHWA, *Highway Traffic Noise Impact Identification and Mitigation Decisionmaking*, was made available. In this report, it was noted "The determination of the reasonableness and feasibility of abatement is often the most difficult part of the analysis" (*7*). As had been noted in the 1982 memorandum, the 1989 report stated, "Feasibility deals primarily with engineering considerations . . ." whereas "Reasonableness should be based on a number of factors—not just one criterion" (*7*). The 1989 report actually detailed some of the reasonableness criteria that could be applied. These criteria include noise abatement benefits, the cost of abatement, the views of the affected residents, absolute noise levels, the change in noise levels, the development along the highway, and the environmental impacts associated with the construction of abatement. As the report noted, the "listing is not intended to be all encompassing. Rather, it is intended to indicate some of the factors that should be considered in determining the reasonableness of proposed noise abatement measures. Each SHA should develop and utilize its own criteria for determining reasonableness" (*7*).

Florida Department of Transportation, 605 Suwannee Street, Mail Station 37, Tallahassee, FL 32399-0450.

abatement in this situation). Either way, FHWA noted in the 1989 report that antiquity was a factor to be considered in addressing the reasonableness of noise abatement. This point was emphasized by FHWA in the 1997 change to the Code of Federal Regulations (23 C.F.R. Part 772), where it noted in regard to Type II projects (considered retrofit projects) that "noise abatement measures will only be approved for project . . . or are proposed along lands where land development or substantial construction predated the existence of any highway" (5). The issue of antiquity often conflicts with the viewpoint of the affected receivers and their elected officials, both of whom believe that, regardless of when the affected receivers came into being, FDOT owes them a noise barrier. This type of conflict often results in economic reasonableness factors being discarded in favor of reaching a prompt resolution that satisfies the aggrieved party.

In summary, FDOT has used numerous reasonable and feasible factors over the years to guide its decision-making process on noise abatement. These factors, unfortunately, have never been officially ranked in terms of priority, but cost has always been the unofficial top priority element once it was determined that an appropriate noise reduction could be achieved. This concern has led FDOT to attempt to prioritize the process and make it as simple as possible so that the decision-making process will be consistent from project to project and less likely to be driven by political or cost issues.

ALTERNATIVE APPROACH

A different approach to the determination of feasible and reasonable when it comes to traffic noise abatement would refocus the 21 factors currently used in this determination. The following sections address the factors.

Feasibility Factors

Feasibility would encompass seven factors (it currently involves two). These factors would include the following:

1. Can a 5-dB (or more) insertion loss be provided to the impacted receivers as long as the cost, visual impacts, or similar issues are not too great? If not, this will be considered a fatal flaw.
2. Can the abatement measure be designed and constructed without creating a safety hazard to either the motorist or the adjacent properties? For example, would the placement of a noise barrier impact sight-distance, thereby creating a dangerous driving condition? If so, this will be considered a fatal flaw.
3. Will the construction of the abatement measure adversely affect reasonable accessibility of adjacent property owners to the roadway? If so, this will be considered a fatal flaw.
4. Can the noise barrier planned actually be constructed using ordinary construction methods and techniques? Would the placement of the noise barrier require unique equipment that is not generally available to most contractors? Are there drainage ways, steep slopes, river, or lakes that create such a difficult construction environment that costly equipment will be required? If this is the case it will be considered a fatal flaw.
5. Maintenance issues might also render a noise barrier design as being not feasible if the effort and cost associated with maintaining a barrier are unreasonable. For example, a tall barrier placed on a bridge over water may make bridge inspection extremely difficult or dangerous, or both, because it eliminated the use of ordinary means such as snooper trucks. This would result in a fatal flaw condition.
6. Right-of-way needs, including access rights, easements for construction and/or maintenance, and additional land needed to build the barrier must be considered. Impacts on existing legally permitted outdoor advertising must also be considered. If right-of-way issues cannot be overcome, they may be considered a fatal flaw unless a reasonable alternative can be found.
7. Unique or special land use conditions may also exist that may render a noise barrier as either unreasonable or not feasible.

The view of the affected receivers is also an important factor in determining whether abatement is feasible. FHWA and FDOT both have taken a very strong position in this regard. However, the full desires of the impacted and potentially benefited public may not be known at the early stages of project development. Therefore, this potentially fatal flaw will not be considered as part of this quantitative process but certainly could be a significant issue during the design phase public involvement process. Indeed, public comment has resulted in a number of FDOT noise barrier projects being halted. This is a direct result of public involvement during the design phase. Therefore, the affected public's input would be solicited throughout the project, but it would not be used as a quantitative factor as part of this methodology. It could, however, lead to the later determination that abatement is not desired at a given location and thereby constitute a fatal flaw.

Reasonableness Factors

In an attempt to reduce the subjectivity of determining the reasonableness of noise abatement, a method has been developed to assign point values for a group of common factors that must be addressed each time a noise barrier is proposed. The general idea behind the process is to create a method by which a noise specialist could conduct a noise study and be able to recommend noise abatement where needed and warranted. The goal is to make this decision at the earliest possible time in the PD&E phase, with assurance that the decision was reasonable and the process was uniformly applied.

Assuming that the potential fatal flaws identified in the section on feasibility do not exist or that they can be overcome using reasonable alternatives, the noise specialist would review eight reasonableness factors, such as:

- Cost,
- Antiquity,
- Land use stability,
- Average insertion loss,
- Future noise levels compared with the appropriate abatement criteria,
- Difference between the build and no-build noise levels,
- Relative increase of noise levels between existing and future build conditions, and
- Number of benefited noise sensitive units.

A ninth factor will be considered when all of the other factors have been examined. Has the local government enacted any law or ordinance or implemented a comprehensive land use plan that is designed to minimize or prevent noise sensitive land uses from being built adjacent to an existing or proposed highway? If so, bonus points will be added to the score as a reward for the efforts.

Here is how the process is anticipated to work. Each factor is given a rank and a weighting value, as shown in Table 1.

be built at a reasonable cost. Because no barrier is to be designed and built that provides less than 5 dB of insertion loss for those identified as affected receivers, a value below that level would be considered a fatal flaw. To assess the value of the average insertion loss at the benefited receivers, the following scale is applied:

Average Insertion Loss	*Factor Value*
≥9 dB	5
8 dB	4
7 dB	3
6 dB	2
5 dB	1

Example: Using the weighting value of 3, a noise barrier that provided an average insertion loss of 6 dB per benefited receiver would be assigned a value of 6 points ($2 \times 3 = 6$).

Future noise levels compared with the abatement criteria, with a weighting value of 3, is a reasonableness factor that focuses on the relative difference between the future noise levels compared with levels set by FHWA for NAC Category B. The implication is that the more the noise level is predicted to exceed the activity category, the greater the impact and the more desirable it is to reduce this level through the application of noise abatement. Therefore, to assist in this evaluation, it is determined by how many decibels on average the future noise level will exceed the NAC, and then the following scale is applied:

Average dBs over NAC	*Factor Value*
≥8	5
6–<8	4
4–<6	3
2–<4	2
1–<2	1

Example: Using the weighting value of 3, a project that is expected to exceed the NAC for Category B land use by an average of 5.5 dB would be assigned a value of 9 points ($3 \times 3 = 9$).

The difference between the build and no-build noise levels, with a weighting value of 3, is a reasonableness factor that focuses on the relative increase of future noise levels compared with the noise levels that would result whether the project was built or not. The implication is that the more the noise level is predicted to increase as a direct result of the project rather than the projected growth in traffic, the greater the impact and the more desirable it is to reduce this level through the application of noise abatement. Since most people cannot distinguish a change of less than 3 dB, any change below this level is viewed as having a minimal impact. Therefore, the average difference in decibels between the build and no-build noise levels is determined, and the following scale is applied to assist in the evaluation:

Average dB Difference	*Factor Value*
≥7	5
≥6 but <7	4
≥5 but <6	3
≥4 but <5	2
≥3 but <4	1

Example: Using the weighting value of 3, a project that is expected to have an average future noise level difference of 5.5 dB between the build and no build options would be assigned a value of 9 points ($3 \times 3 = 9$).

The relative increase from existing to the future build option, with a weighting value of 3, is a reasonableness factor that focuses on the relative increase of future noise levels as compared to the noise levels that currently exist. The implication is that the more the noise level is predicted to increase as a direct result of the project and increased growth in traffic, the greater the impact and the more desirable it is to reduce this level through the application of noise abatement. Because most people cannot distinguish a change of less than 3 dB, any change below this level is viewed as having a minimal impact. Therefore, the average difference in decibels between the existing and the future build option noise levels is determined, and the following scale is applied to assist in this evaluation:

Average dB Difference	*Factor Value*
≥15	5
≥12 but <15	4
≥10 but <12	3
≥5 but <10	2
≥3 but <5	1

Example: Using the weighting value of 3, a project that is expected to have an average future noise level difference between the future build and existing noise levels of 13 dB would be assigned a value of 12 points ($4 \times 3 = 12$).

The number of units to be protected as a result of the abatement effort, with a weighting value of 2, is a reasonableness factor that focuses on the number of benefited receivers that will result from an abatement effort. A benefited receiver is defined as one that will receive 5 dB or more of noise reduction as a direct result of the abatement effort. The implication is that the more benefited receivers, the more efficient the abatement will be and the greater the community benefits will be, and the more desirable it is to provide the abatement. Because the minimum number of benefited receivers must be one, this has been assumed to be the lowest starting point. Therefore, the following scale has been established to assist in this evaluation:

No. of Benefited Receivers	*Factor Value*
≥5	5
4	4
3	3
2	2
1	1

Example: Using the weighting value of 2, a project that is expected to provide a benefit of 12 dB in reduction from the construction of a noise barrier for three homes would be assigned a value of 6 points ($3 \times 2 = 6$).

Finally, an additional consideration should be made about the reasonableness of abatement. Has the local government enacted any law or ordinance or implemented a comprehensive land use plan that is designed to minimize or prevent noise sensitive land uses from being built adjacent to an existing or proposed highway? Are the developers providing adequate provisions in the design of projects to eliminate the impact of highway traffic noise? Additionally, does the local government enforce these requirements? If the answer to these questions is affirmative, then an additional 5 points can be added to the total of the other eight factors and be used in the determination of the reasonableness of the noise barrier. The idea behind these points is to reward local governments that are actively seeking to prevent or minimize adverse impacts on future development from highway noise. At the same time, this might serve as an incentive to those local governments that have not enacted controls to do so. This idea is consistent with FHWA's approach of placing more emphasis on local land use controls to improve compatible environments along highways.

Once all of the reasonableness factors have been evaluated, the reasonableness of providing abatement can be determined. This is done by totaling all of the values obtained from the evaluation of the eight factors. The resulting total is then compared with the range of values found as follows; the reasonableness of providing abatement will be defined. As with any effort to define a series of subjective factors, there will always be some projects that fall in that area where the rea-

Promoting Environmental Stewardship in Transportation

Maintenance and Operations at the New York State Department of Transportation

Debra A. Nelson, Gary R. McVoy, and Laura Greninger

The New York State Department of Transportation (NYSDOT) is firmly committed to a proactive environmental ethic in providing a safe, efficient, balanced, and environmentally sound transportation system in the state of New York. This includes conducting maintenance, equipment management, and construction activities appropriately to prevent and minimize adverse impacts on the environment and to enhance the environment whenever possible. The maintenance and operations at NYSDOT show how the operational capabilities of a department of transportation can be brought to bear on the environmental stewardship responsibilities shared by all governmental organizations.

Historically, transportation agencies have progressed their capital programs in a way that ensures strict regulatory compliance. However, they seldom went above and beyond compliance. Although a reactive approach served to reduce unnecessary environmental damage, it did little to improve the environment.

It is the responsibility of all state agencies, not just that of the environmental agencies, to protect the environmental resources within the state. As New York's largest public works agency, the New York Department of Transportation (NYSDOT) recognizes its potential and opportunity to proactively advance the state environmental program. NYSDOT has affirmed its obligation and responsibility to the people of New York to protect, improve, and enhance the environment as opportunities arise, especially when this can be done for little or no additional cost.

To address this obligation, NYSDOT developed an Environmental Initiative in the spring of 1998. Through proactive actions, NYSDOT has become an important part of New York State's environmental solution and has changed its working relationships with environmental agencies and groups. As these agencies and groups have become partners, permit approval times have been reduced, mitigation costs have declined, morale has improved, and cost-effective environmental benefits are being realized. By progressing the philosophy of environmental stewardship, NYSDOT has moved beyond the conventional reactive regulatory compliance to that of protecting and enhancing the environment. The Environmental Initiative is a paradigm shift applicable to all public works agencies.

New York State Department of Transportation, Environmental Analysis Bureau, 1220 Washington Avenue, Building 5, Room 303, Albany, NY 12232-0473.

BACKGROUND

NYSDOT is the state's largest public works agency. Accordingly, the department recognizes its obligation and responsibility to the people of New York State as it conducts its business of planning, building, and maintaining a transportation system. Environmental stewardship builds on the values of the department's employees to protect the natural and cultural resources of the state. Caring for the environment while providing a transportation network allows NYSDOT employees to feel good about being good neighbors, ones whom a community or an individual welcome rather than shun. Environmental stewardship builds credibility, trust, and goodwill as well as improves staff enthusiasm and morale.

NYSDOT's ENVIRONMENTAL STEWARDSHIP PROGRAM

NYSDOT's Environmental Initiative began in April 1998 with the creation of the Environmental Initiative Statement (see http://www.dot.state.ny.us). Following kickoff activities throughout the summer of 1998, Governor George Pataki formally announced the Environmental Initiative on October 20, 1998. Since that time, NYSDOT has undertaken deliberate actions and proactively approached addressing environmental matters.

Objectives

NYSDOT's Environmental Initiative has five major objectives:

- Promote and strengthen an environmental ethic throughout the department;
- Advance state environmental policies and objectives with NYSDOT resources;
- Partner with others to construct environmental enhancements;
- Pilot new environmental protection and enhancement methods; and
- Strengthen relationships with environmental agencies, organizations, and local municipalities.

Action Plans

Each of the 11 NYSDOT regions and main office functional units has been directed to prepare an action plan for its program to address

• Including lists of Environmental Initiative projects in the annual Capital Program Update;
• Publishing periodic environmental accomplishment books;
• Formally recognizing NYSDOT teams or individuals for outstanding environmental accomplishments;
• Establishing an environmental stewardship website (http://www.dot.state.ny.us/eab/envinit.html);
• Identifying, tracking, and reporting environmental accomplishments;
• Receiving recognition for environmental accomplishments by letters of commendation or awards; and
• Receiving or initiating positive media coverage for environmental contributions.

ENVIRONMENTAL STEWARDSHIP IN MAINTENANCE AND OPERATIONS

NYSDOT has made a concerted effort to ensure that environmental stewardship objectives are incorporated into its maintenance and operations activities. Transportation maintenance and operations activities are typically associated either with work conducted along the right-of-way or as facility-based activities conducted at a residency or shop. These operations activities must comply with various and complex federal and state environmental regulations and avoid or minimize environmental impacts. With the implementation of the NYSDOT Environmental Initiative, the department has moved beyond strict regulatory compliance and mitigation to embrace an environmental stewardship and partnership approach.

Environmental Handbook for Transportation Operations

NYSDOT has developed its *Environmental Handbook for Transportation Operations* to provide general awareness and guidance of the primary environmental responsibilities associated with the types of activities conducted by NYSDOT operations staff. The handbook describes the environmental requirements associated with the operation, type of facility, or equipment. This guidance serves as a summary of typical issues and as a flag for certain issues that may require more assistance from the NYSDOT Landscape/Environmental staff or other appropriate personnel. The *Environmental Handbook for Transportation Operations* can be found on the NYSDOT website at http://www.dot.state.ny.us/eab/oprhbook.html.

Environmental Initiative Checklist for Maintenance and Operations

To face the challenge of routinely incorporating environmental components into maintenance and operations, NYSDOT staff developed an extensive list of maintenance improvement areas that support the Environmental Initiative. Some of the primary issues include reducing waste, reducing pesticide and chemical applications, improving water quality, and improving aesthetics (such as landscaping).

General operations activities identified include the following:

• Reusing and recycling various materials, including pavement;
• Improving environmental factors of facilities through use of the following:
  —Oil and water separators,
  —Sewer connections,
  —Salt storage buildings,
  —Energy conservation measures, and
  —Visual screening;
• Implementing of erosion control and vegetation management (e.g., using mowing guidelines and herbicide controls);
• Improving roadside appearance (e.g., adopt-a-highway and graffiti abatement); and
• Cleaning pavement with biodegradable agents.

Snow and ice operations activities identified include

• Training of personnel in snow and ice control treatments and equipment calibration to reduce material use;
• Training of municipal snow and ice contractors and local departments of public works (DPWs) in snow and ice control techniques;
• Testing and use of new snow and ice equipment, including onboard liquid systems and temperature sensors; and
• Testing and using new materials for prewetting or anti-icing applications, such as magnesium chloride, agricultural products, salt brine, and calcium chloride.

Bridge-specific operations activities identified include

• Using bioengineering techniques for stream stabilization,
• Conducting clearing and snagging and scour protection of streams,
• Cleaning bridges in an environmentally sound manner according to specification,
• Restricting stream work dates to protect fisheries,
• Installing fish passages,
• Improving habitat, and
• Protecting riparian habitat.

Besides conducting maintenance activities in an environmentally sensitive manner, the NYSDOT maintenance program is proceeding to the next step, to improve and enhance the environment. The following are examples:

• Conducting outreach to county and local DPWs on all of the foregoing techniques,
• Providing an online publication of the *Environmental Handbook for Transportation Operations*,
• Building fishing access sites,
• Constructing boat launch sites,
• Installing signs for historic sites,
• Erecting interpretive kiosks,
• Installing peregrine nest boxes on bridges,
• Installing kestrel and bluebird boxes along the right-of-way,
• Providing landscaping around maintenance facilities, and
• Developing and testing alternatives to herbicide use.

As a quality assurance measure, maintenance staff have developed an Environmental Initiatives checklist to track the environmental practices performed by maintenance staff in the residencies, by bridge crews, and by special crews. The report is completed by the regional managers and reported annually to the main office program manager. This allows the program area to pilot new techniques and reevaluate the effectiveness and extent of implementation of

Paper No. 02-3681

Integrated Approach for Identifying Potential Environmental Issues of Proposed Transportation Corridors

Ilir Bejleri, Paul Zwick, and Andrew Lyons

Transportation projects often have delays, unnecessary duplication of efforts, and especially a lack of coordination among the involved agencies, leading to extra costs associated with the environmental review and approval process. The Florida Department of Transportation and University of Florida researchers are exploring several strategies for developing software tools to address such concerns. The goal is to identify major issues of the proposed transportation projects early in the planning phase so appropriate stakeholders can consult and resolve those issues before additional resources are invested in the project. Proposed is a methodological framework and a conceptual system design for building these software tools. The methodology for analyzing the impact is conceptualized as object-oriented, modular, and highly customizable. This approach offers analysis consistency and great flexibility for applications anywhere in the United States, provided that spatial databases are available. The system design strategy proposed for implementing the methodology takes an integrated approach between geographic information systems and relational database management systems. A prototype application developed based on the proposed framework proved effective in confirming the primary impact issues in a road extension pilot study in Florida. The tool quickly analyzed each of the proposed alignments and compared the levels of impact. Future directions will include expanding the focus from impact assessment to decision support with capabilities for selecting optimal road alignments.

In 1998, the Congress passed the Transportation Equity Act for the 21st Century (TEA-21), which included a requirement for "Environmental Streamlining" (*1*). Section 1309 of the act addresses concerns relating to delays, unnecessary duplication of effort, and added costs often associated with the environmental review and current approval process. Environmental streamlining calls for effective and timely environmental review decisions and for complete, earlier, and better coordination and participation by all federal, state, and local agencies involved in the decision-making process, to reduce conflicts and their associated costs and delays.

The Florida Department of Transportation (FDOT), in acknowledging similar problems with the environmental review at the state level, has been making a number of efforts to develop and implement an improved and more efficient transportation planning and environmental review process. One effort was initiated in 1999 when an interagency task force led by the Florida Governor's Office started looking into the methodologies and the processes of identifying potential impacts on the physical environment and nearby communities. This effort led to the development of guidelines and a screening process for identifying environmentally sensitive transportation projects, especially for those with potential secondary and cumulative impacts (*2*). The purpose of these guidelines was to assess the scope and the severity of potential impacts, and to initiate early coordination with the appropriate federal, state, and local agencies and help streamline the environmental review process.

The next logical step was to implement these guidelines into software tools that transportation planners and environmental specialists could use. For this task, FDOT chose to collaborate with researchers at the University of Florida. The goal was to conceptualize a framework for building software tools that would aid transportation planners in identifying the potential environmental impacts of proposed transportation corridors during the planning phase of the project, before the stage pertaining to the National Environmental Policy Act (NEPA) of 1969 (pre-NEPA stage). The approach would have to be generic to be applied anywhere in the state using a standardized methodology. A prototype had to be built and applied to a pilot study in Florida. This paper describes the proposed methodological framework, the conceptual design of the system, the development of the prototype and its application in a pilot study in Florida.

The following two sections give important background information that led to the development of the specific research objectives. The first section describes briefly the environmental screening guidelines for identifying environmentally sensitive transportation projects developed by the intra-agency task force in Florida. The second section gives a brief description of the geographic information system (GIS) and its application in transportation planning.

The subsequent sections focus on the objectives and the methodology of the research. The system design architecture and the implementation of a prototype based on the proposed framework are discussed. An application of the prototype is presented and finally conclusions and future directions for improvement are identified.

ENVIRONMENTAL SCREENING ANALYSIS

Environmental screening analysis is intended to be conducted in response to guidelines developed by an intra-agency task force in Florida. The purpose of these guidelines is to identify, early in the planning phase, major issues of proposed transportation projects that can be consulted on and resolved by the appropriate stakeholders before additional resources are invested in the project. These guidelines contain several criteria that seek to identify potential

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• Presentation of the results in a professional looking, easily understood, and customizable format; and
• Power user tools for creating and analyzing new spatial layers.

There was a final objective. It was to use the prototype in a pilot study in Florida to prove the validity of the proposed framework in confirming the impact issues on a proposed project in that state.

METHODOLOGY

Overview

The environmental issues of concern are seen as impact questions. To assess the potential impact and provide quantifiable indicators or sensitivity indices for measuring impact severity, the analysis determines the spatial relationship between the GIS data layers and the proposed road corridor. For example, to provide an assessment for one of the impact questions such as "Are there wetlands of regional significance in the corridor area?" the analysis looks for an intersection type of spatial relationship between significant wetlands and the corridor. If the result proves positive, the analysis identifies the number and the area of wetlands affected. Then the result is compared against the impact thresholds to finally determine the severity of the impact.

Analysis Object

To make possible the automation of the environmental screening analysis and accommodate all the required impact questions, the analysis is conceptualized as an object with functions and properties instructing the application in how to analyze the GIS data and report the results. The structure of the analysis object is shown in Figure 1.

The core of the analysis object consists of several spatial functions that include the following:

• Intersections and adjacency with vector GIS data such as polygons or lines,
• Proximity to GIS point features, and
• Intersection and adjacency with raster GIS data (cell-based, such as grid data).

The selection of the spatial function is dictated by the type of GIS data sets used in the analysis. Examples of analysis that identify intersection or adjacency with vector GIS polygons apply to area features such as conservation lands, 100-year flood plains, wetlands, rights-of-way, property boundaries, census blocks, and others. Proximity to GIS point features is used when the GIS data are represented as points. Examples in this category include endangered species, hazardous material sites, schools, and others. The spatial function of intersection and adjacency with raster GIS data is employed when the data come in grid raster format. The grid format represents geographic features as square cells. Grid data are created in various ways. Some grid data that represent land cover or vegetation types are created from the classification of the aerial photography. Other grid data are created as a result of GIS analysis and modeling. Examples of the latter available in Florida include biodiversity hot spots, priority wetland habitat, ecological network, and more.

A very important function of the analysis object is the attribute query expression. It allows the selection of those features that are relevant to the analysis. For example, to identify the potential impact on federally defined endangered species in Florida, the analysis makes use of a comprehensive database that contains endangered or

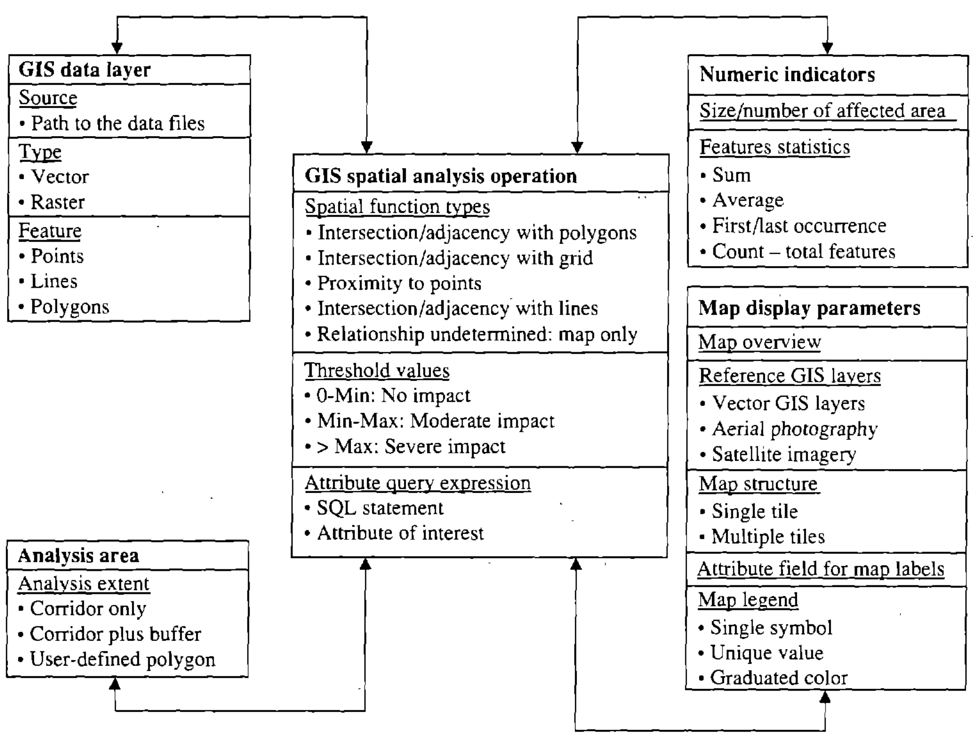

FIGURE 1 Structure of the analysis object.

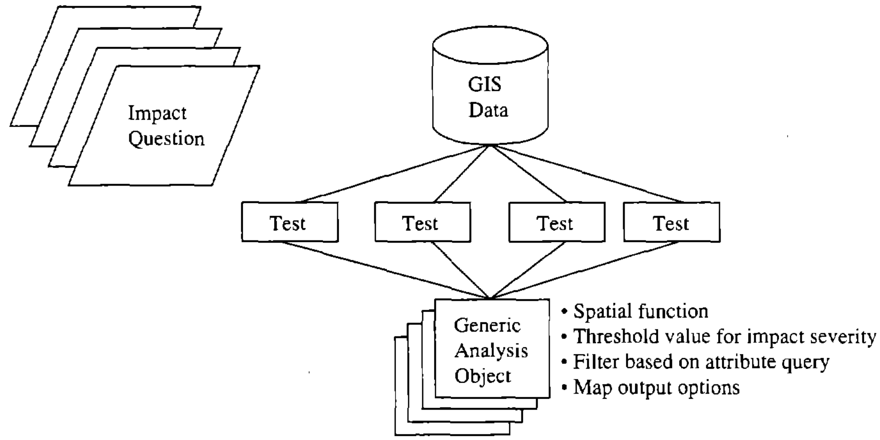

FIGURE 2 Analysis framework.

potential impacts may have to change from one proposed corridor to the other depending on the site characteristics, surroundings, and concerns of the local community.

The output results are automatically compiled into HTML pages and can be shared with the other responsible agencies through the World Wide Web. This solution fulfills an important part of the purpose for designing this system: making the appropriate stakeholders aware of the potential environmental issues up front during planning and before subsequent investments in the project development. Building consensus on the fundamental issues early on in the planning process will streamline project development and implementation and minimize conflicts when it comes to permitting and winning public approval.

PROTOTYPE AND APPLICATION

On the basis of the conceptual system design presented, the research team of the University of Florida developed a prototype called Environmental Screening Analysis Tool (ESAT), a software tool to aid the transportation planning and environmental review process. The prototype is developed using standard commercial GIS and RDBMS software. Both the GIS and the RDBMS are customized to provide the functionality specified in the environmental screening analysis.

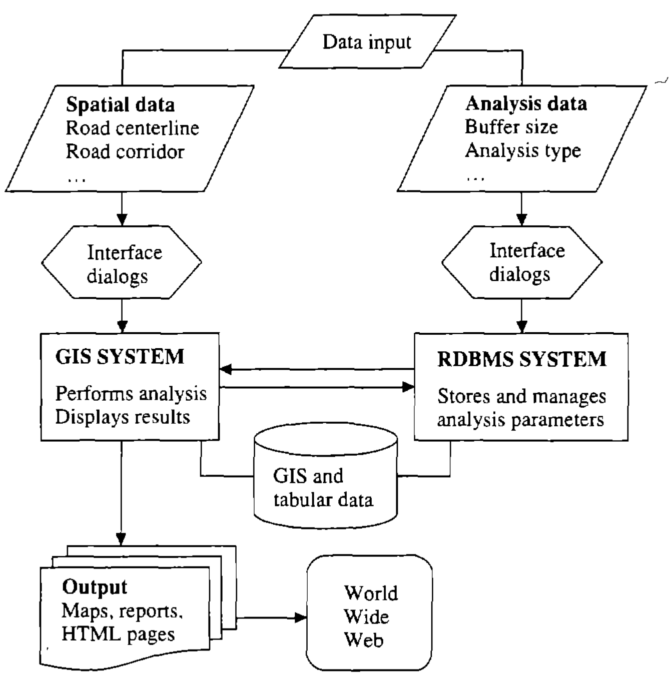

FIGURE 3 System architecture.

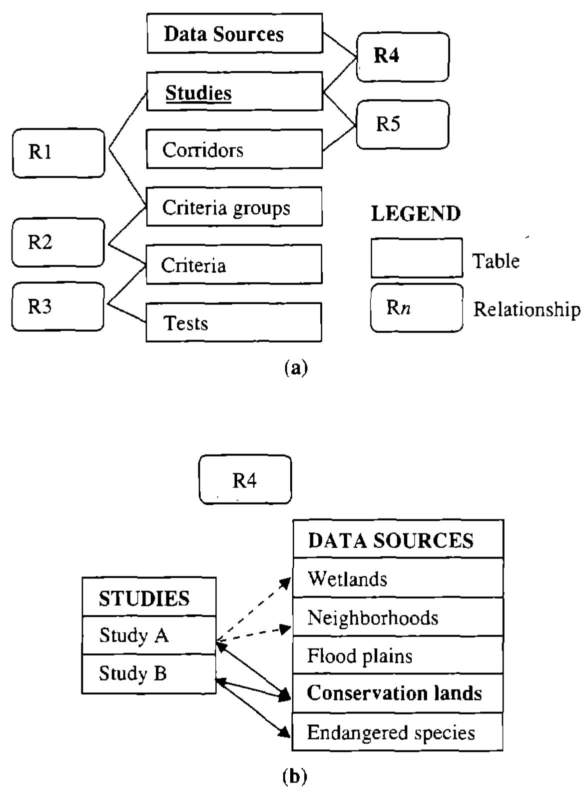

FIGURE 4 Organization of analysis elements in the RDBMS.

impact), a partial map of the affected area, a metadata link to the source of the data used and the table that contains information about the type of each wetland, and the area of each affected wetland located inside the corridor and in the buffer area.

DISCUSSION OF RESULTS

The numeric indicators that determine the level of the impact severity are meant to raise flags where potential impacts may occur. A review team with representatives from the involved agencies will review the analysis results and determine the appropriate actions. It should be noted that the numeric indicators produced by the analysis may not be the only base that the review team will use to determine the severity of the impacts. Although this analysis occurs during the planning phase (pre-NEPA), the conclusive significance of the impact should be a function of both context and intensity, as defined by NEPA (*9*). The impact context should consider the society, the affected region, the affected interests, and the locality. The impact intensity, which refers to the severity of the impact, should include a number of critical issues that need to be considered. Proximity to historic or cultural resources, entities listed in the National Register of Historic Places, endangered or threatened species or their habitats, wetlands, and ecologically critical areas, to mention a few, should be considered in evaluating the impact intensity (*9*).

The proposed methodology conducts a screening analysis and not a detailed environmental or growth management evaluation. However, it does allow a wide range of customizations that give the analysts the flexibility to consider the context of the proposed transportation projects in terms of local settings and circumstances. First, the application provides the choice of different buffer sizes for different criteria. Second, the study area of the impact on the physical environment that is typically defined as a regular buffer around the corridor can be different from the study area of the impact on the community, which should follow the community boundary. Third, the thresholds used to determine the impact significance are not constants but rather variables. When assigning the thresholds, the analyst would use professional judgment to consider the context of the proposed project, unique characteristics of the geographic area, potential cumulative effect of individual impacts, and more. Fourth, a number of criteria used to determine the impact on physical environment and on the community included in the screening analysis, are part of the NEPA issues used in the definition of the impact intensity. The analyst can selectively choose these criteria; other criteria that are applicable to the locality or the region can be defined and added for consideration.

Although the application provides choices to address the uniqueness of different studies and their impacts, the critical interpretation of the impact severity measurements in the light of the context and intensity parameters, and ultimately the recommendation of the appropriate actions, are the responsibilities of the review team. The review team should determine the severity of the impact based not only on the value of the numeric indicators produced by the analysis but also based on the circumstances under which the impact is considered. For example, in a given study, Alternative A may affect less wetland acres in comparison with Alternative B. However, by looking at the geographic characteristics of the area, the review team may find that Alternative A cuts through the wetland by splitting it in two isolated areas, an action that may severely affect the wetland habitat. On the other hand, Alternative B, which has an impact on a larger area of the wetland, may be more peripheral to the wetland, thus causing less impact on the overall health of the wetland.

CONCLUSIONS

The prototype tool developed based on the proposed analysis methodology and system design architecture proved effective in confirming the primary impact issues, including impact on the nearby wetlands and a drainage basin, which provides drinking water for Palm Beach County in Florida. The tool was also able to quickly analyze each of the eight proposed alignment options and compare the levels of impact.

Although the prototype described here was applied in Florida, the method on which the prototype is built is generic and can be applied to other study sites elsewhere. The framework presented in this paper promises to be extremely useful for helping transportation planners share data and impact methodology especially if it uses statewide databases, like the example of the FGDL. Users can tap into this rich compilation of spatial data or supplement it with their own data. Users can also develop and share analysis. For example, a habitat specialist can define a test to identify potential impact on strategic habitat and post the test to the central online database, where it can be shared by other users that have access to the same data.

Currently, all analyses are based on a simple measure of the area of intersection between the analysis area for the corridor and the theme representing affected features. However, additional types of analyses can be incorporated if a methodology can be conceptualized. For example, a measure of the average distance of public transit points to the new road could be added to the application if this statistic is helpful. Multiple-theme analyses are also possible. For example, the application could be equipped to calculate the number and area of parcels zoned for agriculture, which also fall within growth area of the county's comprehensive plan and fall within 2 mi of the road. Environmental impacts as well as socioeconomic impacts and jurisdictional issues can be studied if appropriate data are available. Any type of question whose answer depends in part on a geographic relationship with the proposed corridor may be potentially integrated into the system.

Although the proposed methodology is capable of generating numeric indicators and spatial outputs that can support other studies, it is not intended to replace traditional, more rigorous methods of environmental impact evaluation. Its main purpose is to quickly identify potentially significant impacts and initiate early coordination among the stakeholders involved, before more resources are invested in the project.

The results produced by the proposed analysis methodology will be only as accurate and up to date as are the data used. For example, statewide habitat coverage digitized at 1:100,000 may be accurate only to within 500 ft. This may be fine for large-scale analyses, but it may result in a high margin of error when trying to determine habitat affected by a 220-ft-wide corridor. Likewise, a census coverage that is 10 years out of date will likely underestimate any demographic measures for community impact assessment. Providing metadata with the GIS data used is very important for the correct interpretation of the results.

Currently, the research team is focused on extending the pilot base among a greater number of transportation planners, including metropolitan planning organizations in Florida. A second direction is the expansion of the scope of the numeric indicators and the number of criteria and tests based on the user feedback.

Paper No. 02-3547

Tiered Environmental Studies in the National Environmental Policy Act Process for Highway Projects

William G. Malley and Angela M. Dusenbury

In recent years, there has been a renewed interest in the use of tiering and tiering-like procedures as techniques for managing the National Environmental Policy Act (NEPA) process for highway projects. However, experience with these procedures remains limited, and guidance materials are scarce. Thus, available information is brought together about tiering, the benefits and drawbacks of tiering are assessed, and general advice is offered about when to use tiering and what issues to consider in a tiered NEPA process. The effort consists of five parts. First is an introduction of NEPA and its processes, followed by information on regulatory authority and guidance, early experiences with tiering, recent developments in tiering, benefits and drawbacks of tiering, and issues to consider in preparing a tiered study.

Tiering is a procedure for completing the National Environmental Policy Act of 1969 (NEPA) process in two separate stages, known as tiers. The first tier involves the preparation of an environmental impact statement (EIS) that examines a large land area or a broad set of issues associated with a major federal action that triggers the NEPA process. The second tier generally involves the preparation of several separate NEPA documents, which could include EISs, environmental assessments (EAs), or even categorical exclusions (CEs).

Tiering is frequently used by federal agencies that are required by law to prepare comprehensive land management plans (e.g., the U.S. Forest Service), but it has been much less frequently used for linear actions, such as highways. The reluctance to employ tiering for these projects has resulted from several factors: a general lack of familiarity with the procedure, a perception that previously tiered studies had been unsuccessful, and a belief that tiered studies would only add to the cost and complexity of an already time-consuming and complex process.

Since late 1999, however, FHWA has initiated or completed several tiered EISs. In addition, FHWA has prepared a number of EISs using tiering-like procedures—that is, they have incorporated features of a tiered approach within the context of a traditional, nontiered process. Finally, a number of states have begun to initiate NEPA studies during the statewide and metropolitan transportation planning process; as part of that effort, at least one state has adopted procedures calling for the preparation of tiered NEPA studies, with a first-tier study taking place during the planning process.

Taken together, these developments reflect a renewed interest in tiering as a means of managing the NEPA process for large and complex highway projects. However, agencies' experience with these procedures remains limited, and guidance materials are still relatively scarce. This paper brings together the information that is available about tiering, assesses the benefits and drawbacks of tiering, and offers advice about when to use tiering and how to approach a tiered NEPA process.

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REGULATORY AUTHORITY AND GUIDANCE

The use of tiering for highway projects is governed by the regulations issued by the Council on Environmental Quality (CEQ), which are codified at 40 C.F.R. (Code of Federal Regulations) Part 1500, and under the regulations issued jointly by FHWA and FTA, which are codified at 23 C.F.R. Part 771. (For purposes of this paper, the joint FHWA/FTA regulations will be referred to as the FHWA regulations.) Both CEQ and FHWA also have addressed tiering in guidance documents. For highway projects, the most specific and helpful guidance is contained in a June 18, 2000, memorandum issued by FHWA headquarters.

CEQ Regulations and Guidance

The concept of tiering first appeared in the CEQ regulations in 1978, and the regulatory language regarding tiering has remained unchanged since that time (*1*). The regulations define tiering as "the coverage of general matters in broader environmental impact statements . . . with subsequent narrower statements or environmental analyses . . . incorporating by reference the general discussions and concentrating solely on the issues specific to the statement subsequently prepared" (40 C.F.R. § 1508.28). The regulations also state that tiering should be used "to eliminate repetitive discussions of the same issues and to focus on the actual issues ripe for decision at each level of environmental review" (40 C.F.R. § 1508.20) and as "a means of accomplishing the NEPA requirements in an efficient manner as possible" (*2*).

CEQ explained its tiering regulations in its "Forty Questions" guidance in 1981. In that guidance, CEQ noted that on actions covering a broad area, such as large highway projects, a broader or overview EIS can serve as a valuable tool to analyze the project's potential direct, indirect, and cumulative impacts on the affected environment (*3*). CEQ encouraged the use of tiering in these situations to "avoid duplication of paperwork through the incorporation by reference of the general discussions and relevant specific discussions from an environmental impact statement of broader scope into one of lesser scope or vice versa."

CEQ addressed tiering again in guidance issued in 1983. In that guidance, CEQ reiterated its view that Tier 2 documents could avoid duplication of paperwork, by summarizing the issues raised in Tier 1

—The third part of the test requires that actions "not restrict consideration of alternatives for other reasonably foreseeable transportation improvements." The FHWA memo noted that this requirement "is perhaps the most challenging" in the context of a tiered NEPA process. The memo explained that this requirement is "focused on avoiding undesirable outcomes . . . rather than simply preserving the ability to consider alternatives in the abstract." Therefore, it recommended "structuring the decision making so that the first tier strategic choices . . . not restrict the second tier location and design decisions to alternatives which have highly undesirable consequences, such as unusually severe impacts to communities or the natural environment that might have been avoided with a different first tier strategy."

- The memo recommended "using the first tier DEIS to identify proposed subsections (rather than initial thoughts) for the second tier analysis." The memo pointed out that flexibility can be maintained "by communicating that the subsections are subject to refinement based on comments received."
- The memo stated, "criteria used for establishing subsections [for Tier 2] should take into account both the purpose and need for the subsection projects, and avoiding 'pointing a loaded gun' at an important resource(s) beyond the subsection." The memo also provided some specific examples of how these considerations might affect the designation of break points for the Tier 2 projects.
- The memo stated that, to provide "a framework for flexible decision-making at the second tier," each of the second tier analyses should "look beyond the subsection termini to adjacent subsections for which second tier analyses have not yet been undertaken to ensure that one project doesn't point the 'loaded gun' at resources associated with the adjacent project."

EARLY EXPERIENCES WITH TIERING FOR HIGHWAY PROJECTS

In the late 1980s, FHWA advocated the use of tiering as a means of supporting corridor-preservation efforts in high-growth areas. At that time, FHWA noted the increasing urgency of "ensuring that viable locations will exist for building future highways in the developing fringe of the Nation's metropolitan areas" (FHWA Memorandum from Associate Administrator for Right-of-Way and Environment to Regional Federal Highway Administrators re: Highway Corridor Preservation and Early Right-of-Way Acquisition, July 1, 1988). FHWA also expressed concern that the conventional project development process, in which right-of-way acquisition immediately precedes construction, does not recognize the fact that the optimum time for acquisition differs from the optimum time for construction. To address the need for earlier corridor preservation, FHWA proposed the use of tiered NEPA studies, under which corridor-preservation activities would be authorized at the end of Tier 1.

In keeping with this policy, FHWA initiated a number of tiered EISs in the late 1980s and early 1990s. However, for a variety of reasons (most of which had nothing to do with tiering), many of those studies were never completed. Prominent examples of tiered EISs that were never completed include the following projects:

- Washington, D.C., Bypass (Maryland and Virginia). In the 1980s, the Maryland State Highway Administration (SHA) proposed an eastern bypass, which would stretch from I-95 in Northern Virginia to the Routes 50 and 301 in Maryland for a distance of approximately 93 mi. The Virginia Department of Transportation proposed a western bypass, from I-95 in Northern Virginia to I-70 in Maryland for a distance of approximately 82 mi (*5*). In 1989, FHWA issued a single notice of intent to prepare a Tier 1 EIS that would consider both projects together. The purpose of the study was to locate corridors that would provide a basis for ROW preservation in areas subject to the most intense development pressures (*6*). The study area encompassed 5,100 mi^2 and covered two states and 23 counties. However, concerns over the potential for growth-inducing impacts and a lack of consensus on the location of a Potomac River crossing led to the abandonment of the study. In 1996, the project was revived and refocused only on the western bypass, a shorter 50-mi-long Western Transportation Corridor (WTC). The DEIS for the WTC project is in progress.
- Las Vegas Beltway (Nevada). In 1992, FHWA began a Tier 1 EIS to adopt a corridor location for the northern and western portions of a beltway around the fringes of Las Vegas (*7*). FHWA approved the Tier 1 EIS on June 7, 1996, and issued a Record of Decision (ROD) on August 5, 1996 (*8*). However, in 1997, Clark County determined that no federal funds would be necessary to complete the project. As a result, FHWA's involvement ended, and no Tier 2 environmental documents were ever prepared (*8*).

In addition to these studies, there were approximately 10 to 12 projects (8 to 10 of which involved new corridors or transportation improvements for highways in California) that used the tiered process from the mid-1980s through the mid-1990s. The earliest projects, which primarily were concentrated in Orange County, California, consisted of Tier 1 studies that evaluated a broad number of options for multimodal facilities to address congestion problems and Tier 2 studies that focused on specific components of those multimodal facilities, such as widening an Interstate or locating an alignment of the new facility (*9–14*). Beginning around 1989, the majority of tiered EISs were used for protecting right-of-way or preserving corridors for highways, particularly in areas of rapid development. FHWA issued Notices of Intent to prepare Tier 1 EISs to define and preserve corridors in these counties (*15–19*):

- Washington County, Oregon, and Contra Costa County, California, in 1989;
- Los Angeles County, California, and Livingston, Michigan, in 1991; and
- Kern County, California, in 1994.

RECENT DEVELOPMENTS

In the past few years, there has been renewed interest in the use of tiering and tiering-like procedures for highway projects. Developments in three areas are worthy of note:

1. Recent FHWA experience with tiered EISs;
2. Recent FHWA experience with EISs that used tiering-like procedures; and
3. Efforts by several states to initiate NEPA review in the planning process, which will involve the preparation of a tiered EIS in at least one state.

Recent FHWA Experience with Tiered EISs

Tiered NEPA studies are currently being prepared by FHWA for several major highway projects, including those below.

ronmental process consisted of two separate DEISs, a single FEIS, and a single ROD. The first DEIS evaluated five separate 2,000-ft-wide corridors; it was followed by a decision document (not a ROD) that identified a preferred corridor for further study. The second DEIS then evaluated specific alignments within the preferred corridor. The second DEIS was followed by a single FEIS and a single ROD, which concluded both the corridor-selection and the alignment-selection phases of the study.

Southeast Arkansas I-69 Connector

The Southeast Arkansas I-69 Connector involved a 40-mi highway segment that links Pine Bluff, Arkansas, to the proposed I-69 Corridor. For this project, the environmental process involved a single DEIS, a single FEIS, and a single ROD—the traditional set of NEPA documents. However, within the DEIS, the analysis of alternatives involved two stages: first, an analysis of alternative corridors, based primarily on GIS data, and then an analysis of specific alignments within a single preferred corridor, based on more extensive field study data (*28*). The use of GIS information in the screening process for this EIS was approved by FHWA headquarters in its April 30, 2001, memorandum discussed earlier. Similar approaches have been used in other states, including Louisiana.

Initiation of NEPA Reviews During the Planning Process

The concept of tiering also is receiving renewed attention in the context of efforts to improve the linkage between transportation planning and the NEPA process. In particular, consideration is being given to the use of a Tier 1 EIS to address the Congress's mandate to eliminate the major investment study (MIS) (23 C.F.R. § 450.318).

In Section 1308 of the Transportation Equity Act for the 21st Century (TEA-21), the Congress directed the U.S. Department of Transportation to eliminate the MIS requirement in FHWA's regulations and integrate the analyses required as part of an MIS into the planning and NEPA processes [TEA-21, Pub. L. No. 105-178, § 1309, 112 Stat 107 (1998)]. Although proposed regulations to eliminate the MIS requirement have been issued, no final regulations have been adopted. However, as a practical matter, the preparation of MIS documents has been discontinued. In the absence of new requirements or specific guidance, states and metropolitan planning organizations have experimented with various approaches to integrating the corridor-level planning process with the project development process. Some of these approaches contemplate the initiation of NEPA studies during the planning process, followed by more detailed NEPA studies during the project development process. Here are some examples:

- Oregon has developed policies that allow for a NEPA document (generally an EIS) to be prepared during the refinement planning process, with the goal of supporting a location decision but not a design decision pertaining to proposed highway improvements (*29*). The Oregon policy calls for a broad-scale NEPA document to be completed (i.e., a ROD would be issued) at the refinement-planning stage, thus clearing the way for right-of-way acquisition within the selected corridor. This policy is intended to facilitate local land use planning, by allowing land use planners to take into account the general location of a future transportation project many years before the project is actually built. The Oregon policy states that further environmental documentation will be required in the design stage. Although the policy does not specifically require that an additional NEPA study be prepared in the design stage, it does state that further NEPA documentation generally will be necessary unless the resulting project qualifies for a CE.
- Indiana has adopted policies requiring the initiation of an EA for major proposed transportation projects when there is not yet consensus on the design concept and scope of the proposed project (*30*). The Indiana policy contemplates that the EA will transition to an EIS at the point where sufficient consensus has been achieved on the design concept and scope for a specific proposed project. Like the Oregon policy, the Indiana policy calls for the initiation of NEPA studies during the corridor planning process. This approach, if successful, shortens project development times by achieving early resolution of major project issues—including purpose and need and the screening of alternatives. However, unlike the Oregon policy, the Indiana policy does not call for the completion of a NEPA study at the planning stage—that is, there is no ROD issued for a preferred corridor during the planning process. As a result, the Indiana policy does not authorize right-of-way acquisition at the conclusion of the planning stage.
- Other states have decided not to initiate NEPA studies during the corridor planning process and instead have continued the traditional practice of preparing feasibility studies (or similar analyses) for proposed improvements at the planning stage. These non-NEPA studies may be similar in scope or content to the NEPA documents prepared by other states during the planning stage, but they generally lack the public and agency involvement and the overall formality of a NEPA study. As a result, non-NEPA studies conducted at the planning stage generally do not provide a basis for resolving purpose and need or other project development issues, nor do they result in authority to acquire right-of-way at the conclusion of the planning stage.

Although none of these policies specifically calls for tiering, the Oregon approach necessarily involves a tiered NEPA process: it requires completion of an initial NEPA study (including a ROD) on location issues in the refinement planning process, followed by an additional NEPA study on design issues in the project development process. This process is time-intensive, but it yields significant benefits: because it results in a completed NEPA study during planning, it allows right-of-way acquisition to take place at the completion of the planning process and results in true finality in the selection of location and mode choice, before the initiation of the project development process.

As this discussion shows, the use of a tiered NEPA process can be a powerful tool for achieving closure on issues of location and mode choice at the end of the planning process. Although it is too early to tell whether tiering will be widely used for this purpose, the need to achieve a better integration of planning and project development is likely to provide an additional impetus for the use of tiered NEPA procedures.

BENEFITS AND DRAWBACKS

To assist practitioners in deciding whether to use tiering, this section of the paper outlines some benefits and drawbacks of the tiered approach. It also briefly outlines the benefits and drawbacks of tiering-like procedures.

Benefits and Drawbacks of Standard Tiering Procedure

The standard tiering procedure involves a full EIS (including a ROD) at Tier 1, followed by multiple NEPA documents for a series of separate actions at Tier 2. This method has both benefits and drawbacks

Defining Purpose and Need

In the context of a tiered NEPA process, it is necessary to consider purpose and need on two levels. In Tier 1, it is necessary to develop a purpose and need for the federal action as a whole. Because the action examined in a Tier 1 EIS is typically very large (often 100 mi or longer), the purpose-and-need statement in Tier 1 typically will focus on broad regional and even national objectives. This broad focus is appropriate for Tier 1, when the alternatives under consideration involve general location and mode choice. However, the broadly defined Tier 1 purpose and need may not be sufficient for purposes of Tier 2 studies. In particular, if the actions examined in Tier 2 involve small subsections of the overall action, it may be necessary to develop more specific statements of purpose and need in each of the Tier 2 studies. Tiering allows the agencies to tailor the purpose and need for each independent segment to comport with local priorities. In such cases, an important challenge for preparers of the EIS is to determine which objectives should be defined in the Tier 1 purpose-and-need statement and which should be defined in Tier 2. In addition, although it is appropriate for different subsections to serve different purposes, it is important to ensure that all purpose-and-need statements—in Tier 1 and Tier 2—are fundamentally consistent with one another in terms of their underlying assumptions and supporting data.

Defining and Analyzing Alternatives

The alternatives in a tiered NEPA process are defined differently at Tier 1 and Tier 2. In Tier 1, an alternative is typically defined in terms of a broad corridor rather than a specific right-of-way. For example, some studies have defined alternatives at Tier 1 as corridors of a fixed width (e.g., 2,000 ft); other studies have defined alternatives as corridors of varying width, which allows the corridor to be narrower in sensitive areas or to be broader in areas where it is necessary to carry forward a wider range of alignments for consideration in Tier 2.

Regardless of which approach is used, the evaluation of broad corridors presents a major challenge—namely, how to evaluate impacts or estimate costs without having even a preliminary definition of the transportation improvement's footprint. One way to address this problem is simply to inventory resources within each of the broad corridors; this approach is frequently used in nontiered studies that involve separate corridor-selection and alignment-selection stages (as in the corridor-level DEIS for Corridor H). Another approach, which is being used on the I-69 project in Indiana, is to develop one or more working alignments within each of the corridors evaluated at Tier 1. The working alignments are used as the basis for developing preliminary estimates of costs and impacts for each corridor.

Determining the Appropriate Level of Detail

Perhaps the greatest challenge in preparing a tiered EIS is determining the appropriate level of detail for the Tier 1 EIS. By definition, the tiered process allows a lower level of detail in a Tier 1 EIS than would be allowed in a traditional, nontiered EIS. However, it often is difficult in practice to determine which analyses must be conducted at Tier 1 and which can be deferred until Tier 2. This difficulty is likely to be greatest when the agencies involved in preparing the Tier 1 EIS have little or no experience with a tiered NEPA process for highway projects.

The basic rule of thumb for determining an appropriate level of detail in Tier 1 is that the detail must be sufficient to allow an informed choice among the alternatives being studied. This rule places the emphasis in Tier 1 on evaluating the relative differences among the corridor-level alternatives (including No Build). This type of evaluation generally will involve three kinds of activities in Tier 1:

1. Inventorying resources located within the corridors,
2. Estimating potential impacts or a range of impacts based on suggested working alignments, and
3. Developing mitigation strategies.

Following are details on those points:

- The task of inventorying resources begins with the compilation of existing information, often using GIS mapping. However, depending on the amount of existing information available, it often will be necessary to gather additional information through field research at Tier 1. The need for additional field research must be determined in consultation with the appropriate resource agencies.
- In addition to inventorying resources within each corridor, the Tier 1 EIS generally will involve some effort to estimate the impacts and costs of constructing the proposed project within each corridor (i.e., within each corridor that is carried forward for detailed study). One way to develop such estimates is to generate working alignments within the corridors, as is being done for I-69 in Indiana.
- Given the limited design detail available at Tier 1, it generally is not possible to develop specific mitigation plans. However, it may be possible to discuss overall mitigation opportunities and strategies for addressing impacts identified at Tier 1.

At Tier 2, the agency examines a range of specific alignments within the corridor selected in Tier 1. The concrete nature of the alignments allows the agency to focus on the specific resources affected by each alignment alternative. Building on the environmental inventory established in Tier 1, the agency is able to identify specific resources impacted rather than making estimates of resources potentially affected. This stage may require the agency to conduct extensive field analyses and consultation with resource agencies, which may require more detail because actual construction is more imminent after Tier 2 than Tier 1. For the second tier, the agency can make a detailed assessment of those impacts and refine its assessments made in the first tier. Furthermore, the agency can develop specific mitigation measures more fitting to the type of resource and impact.

Integrating the Tiered NEPA Process with Other Regulatory Requirements

In the traditional, nontiered NEPA process, the NEPA document must demonstrate that the action will satisfy the requirements of numerous other laws, including Section 106 of the National Historic Preservation Act (NHPA) (16 U.S.C. § 470f), Section 4(f) of the Department of Transportation Act [49 U.S.C. § 303(c)], Section 7 of the Endangered Species Act (16 U.S.C. § 1536), and Section 404 of the Clean Water Act (33 U.S.C. § 1344). Tiered NEPA studies also must meet these same requirements, even though the Tier 1 studies are inherently unable to provide the site-specific detail that would be found in either a traditional, nontiered EIS or in a Tier 2 EIS. Unfortunately, with the exception of Section 4(f), the regulations issued under these other laws do not specifically provide for tiering, nor is there written agency guidance on this topic. As a result, case-by-case interpretation—often at the field office level—generally is needed to determine how to sat-

Habitat Approach to Streamlining Section 7

Colorado Department of Transportation's Shortgrass Prairie Initiative

Marie Venner

Starting in January 2000, FHWA, the Colorado Department of Transportation (CDOT), the U.S. Fish and Wildlife Service, and partners at public and private resource organizations came together to design an impact assessment and advance a mitigation and conservation banking process to aid in the recovery of declining species on Colorado's Eastern Plains. The Shortgrass Prairie Initiative provides programmatic clearance for CDOT activities on the existing road network in the eastern third of Colorado for the next 20 years—through 2022; addresses 3 listed and more than 20 declining species with the greatest likelihood of being listed as threatened or endangered; and covers 90,000 acres of right-of-way in four of CDOT's six regions. The agencies involved sought to invest resources, which would otherwise be spent on a project-by-project clearance process, in more comprehensive and proactive species conservation that would help alleviate the need for further listings and improve predictability in the project development process. Methodologically, the project focused on impacts to habitats rather than species individuals and estimated potential impacts using best available data, supplemented by expert opinion. The resulting project offers programmatic clearance with 1:1 (that is, 1 acre of impact to 1 acre of conservation/mitigation) habitat conservation, regulatory streamlining, cost savings in several categories, and more effective habitat and species preservation. The uniqueness of this project stems from its primary focus on species currently unlisted as federally threatened or endangered, coverage of major as well as minor projects, and the scale at which conservation is being pursued, including planned preservation of approximately 15,000 to 20,000 acres from 2002 onward.

The Colorado Department of Transportation's (CDOT's) Shortgrass Prairie Initiative emerged from several sources. They were a common understanding of the problem at hand, a shared commitment to species recovery and environmental stewardship, opportunities presented by ready analyses of priority conservation areas across the central shortgrass prairie ecosystem, and the willingness among the partners to use all regulatory flexibility to undertake a new approach to conservation and streamlining.

PROBLEM

Species in Peril and Ecosystem in Decline

The central shortgrass prairie ecoregion encompasses approximately 90,700 mi^2 of rolling plains and tablelands dissected by streams, canyons, badlands, and buttes in seven states, from southeastern Wyoming and southwestern Nebraska to northeastern New Mexico, northern Texas, and northwestern Oklahoma. This ecoregion is largely in private ownership and is dominated by shortgrass, mixed-grass, and sand sage prairie (*1*). Figure 1 offers two views. Grasslands are considered to be one of the most imperiled ecosystem types in North America and worldwide; Samson and Knopf wrote in 1994 that "in the larger context of conserving biological diversity in agricultural and natural ecosystems in North America, prairies are a priority, perhaps the highest priority" (*2*). The majority of the ecoregion has been tilled; total losses of native prairie range from an estimated 20% of shortgrass prairie in Wyoming to greater than 99% of tallgrass prairie in Illinois and Iowa (*3*). Grassland birds have shown steeper, more consistent, and more geographically widespread declines than has any other guild of North American species (*4*). At least 50% of the endemic grassland birds are exhibiting significant declines in numbers over large parts of their range (*3*). Bison, once the most significant herbivore on the Plains, has been largely extirpated from the ecoregion (*5*). The black-tailed prairie dog, considered by many scientists to be the second most important herbivore on the western Great Plains in terms of ecosystem maintenance, has significantly declined since the turn of this century (*4, 6, 7*). The black-footed ferret is now considered the rarest mammal in North America (*8*). The Central Shortgrass Prairie ecoregion contains 54 known species considered globally imperiled by state Natural Heritage Programs (*1*). Of these, 10 species are listed as threatened or endangered, 1 species is proposed for listing, and 6 are candidates; another 58 species are endemic, declining, or disjunctive in the ecoregion (*1*).

Not Likely to Adversely Affect Decisions: Project-by-Project Approach

The professionals involved in the Endangered Species Act (ESA) Section 7 consultation process at the U.S. Fish and Wildlife Service (FWS), FHWA, and CDOT shared an observation that the project-by-project process frequently involved a great deal of time and resources, often to less benefit than desired for the species involved. Specialists and engineers work hard to minimize project effects so that a "no effect," or more often a "may affect—not likely to adversely affect" (MA-NLAA) conclusion is possible; however, accumulated MA-NLAAs often do little to assist the species in question, which may continue to decline. Addressing species' needs on a project-by-project basis may only provide limited habitat conservation or improvement strategies, contributing little to the success of individual

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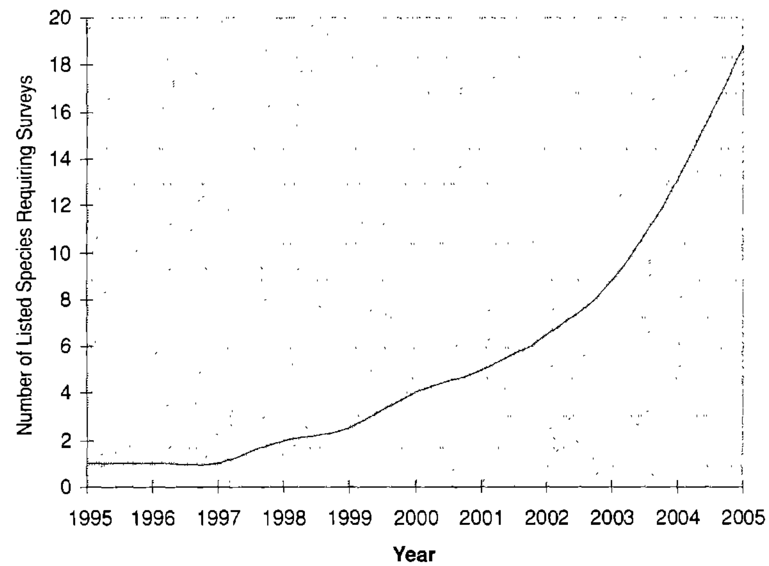

FIGURE 2 Growth of number of Endangered Species Act—listed species in Colorado requiring surveys.

in size and scope on a project-by-project basis, requiring more time spent by CDOT environmental staff and engineers in the regions and at headquarters.

Rising Costs for Projects, Land, and Conservation Measures

The cost of one project delay or temporary shutdown can equal the costs of mitigation for a large number of projects. CDOT figured that with $4 billion worth of transportation improvements planned on the Eastern Plains through 2022, 6 months of delay on 5% of that would equal $15 million. CDOT estimated that project costs are increasing at an average rate of 6% annually. Redesign costs time, money, and headaches. Potential project shutdowns, with the contractor already on site, have even more implications. Although the cost of a potential project shutdown is difficult to estimate due to the large number of factors involved, CDOT considered the question, What is the cost of one project shutdown over 20 years or multiple project shutdowns over 20 years?

Land costs in Colorado are escalating rapidly. Prices in remote areas of Colorado's Eastern Plains have risen more than 50% annually for the past 3 years, more than 100% annually in many cases. Because land was least expensive and unique conservation opportunities existed for prairie dog complexes in the southeastern portion of the state (CDOT Region 2), conservation efforts focused in that area. In one example, a ranch on the New Mexico–Colorado border that was selling for $65/acre in 1996 was selling for $220/acre by 2000. In another case, adjacent ranches in a conservation target area that were selling for $100/acre in 1997 were selling for $250/acre in 2001. Land prices on the exurban fringe (Region 4) along the front range started at a higher level and have also risen steeply, increasing the costs of mitigation adjacent to the right-of-way. Limits on water in remote counties are likely to hinder upward movement of prices for agricultural land in the longer term; these and other factors will make a linear projection inaccurate. However, a conservative projection, based on expected land price increases of 4% to 10% for CDOT rights-of-way annually in remote rural areas and considering limited water and development potential, still led CDOT to estimate that mitigation costs could double in the next 5 years—especially given the recent price increases that were larger than anticipated. See Figure 3.

Listing Threats and Species with Potential for Widespread Impact

Several of the species with a rising listing threat are distributed throughout the eastern third of the state in the central shortgrass prairie, including the following (see Figure 4):

- State bird—the lark bunting;
- Loggerhead shrike;
- Mountain plover;
- Burrowing owl; and
- Cassin's sparrow, which is an indicator species for a large number of other declining bird species.

In addition to the declining bird species, of particular interest in Colorado is the black-tailed prairie dog, also distributed across the eastern third of the state. Described as a "noxious rodent pest" under Colorado state law, the black-tailed prairie dog is regularly exterminated by farmers, ranchers, and increasingly, developers, including CDOT. Following a listing petition in 1998 by the National Wildlife Federation, FWS concluded that listing of the black-tailed prairie dog was "warranted but precluded," but warned state resource agencies that without a concerted and successful conservation effort, the species would be listed. See Figure 5.

The black-tailed prairie dog is one of five prairie dog species in North America, of which two were already listed (in Utah, listed as a threatened species in 1973) and the Mexican prairie dogs (listed as endangered in 1970). Black-tailed prairie dogs existed as part of an historical ecosystem with large herds of bison, covering millions of acres of prairie landscape.

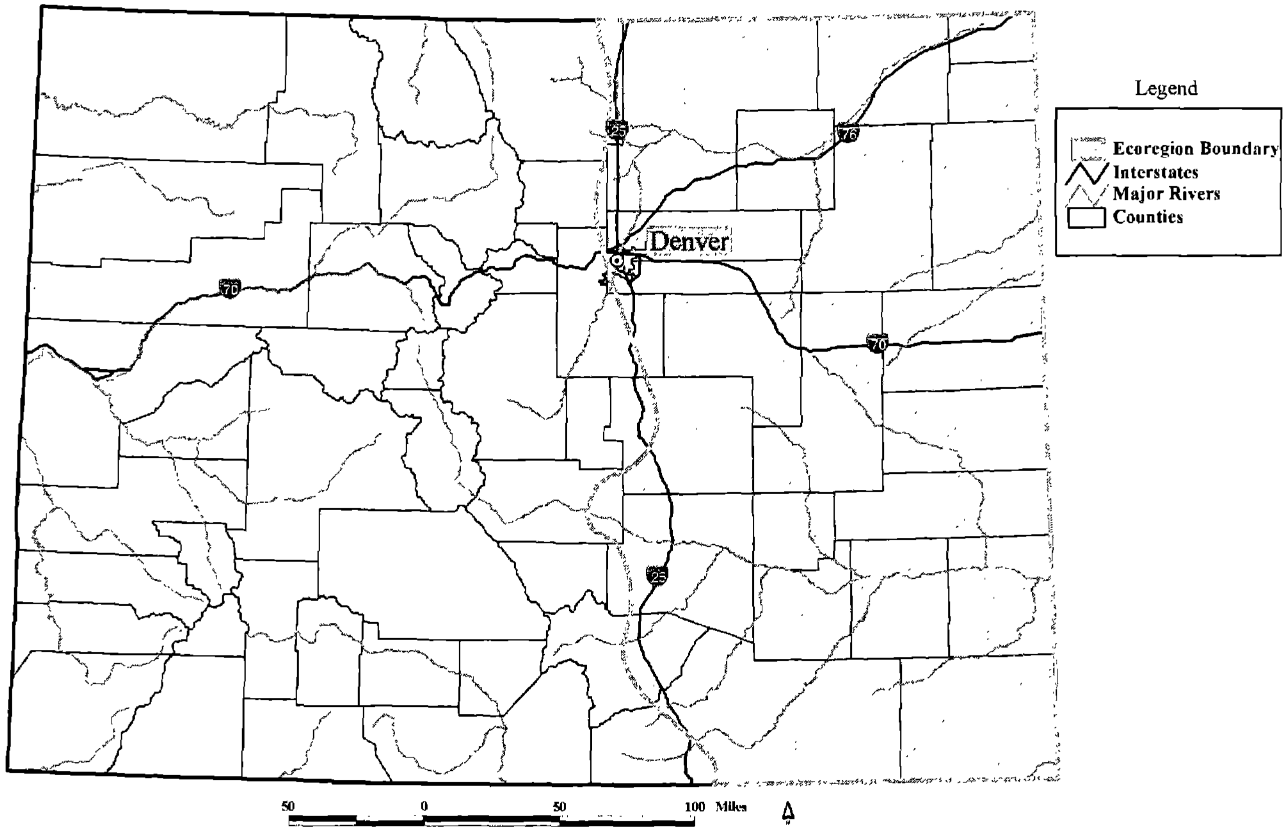

FIGURE 4 Map of Central Shortgrass Prairie in Colorado, range of the black-tailed prairie dog, lark bunting, loggerhead shrike, mountain plover, burrowing owl, and Cassin's sparrow.

> cess of such an initiative. Permits issued to provide assurances for activities to be conducted under a CCAA become effective upon the effective date of a final rule listing any of the covered species as threatened or endangered [see FWS National Marine Fisheries Service and (*10*), pp. 32,705–32,716, in particular p. 32,709].

The final rule allows more flexibility if the permittee is a state or local governmental entity.

FWS' special cooperative relationship with states is further clarified in the agency's July 1994 interagency policy on the role of state agencies in activities undertaken by the Services (that is, FWS and the National Marine Fisheries Service) under the authority of the ESA and associated regulations in title 50 Code of Federal Regulations. That policy recognizes states' "unique position to assist the Services in implementing all aspects of the Act. In this regard, section 6 of the Act provides that the Services shall cooperate to the maximum extent practicable with the States in carrying out the program authorized by the Act."

FIGURE 5 Black-tailed prairie dog.

METHODOLOGY

Under their chosen approach, the agencies sought to cover all declining species likely to be listed under the ESA over the period of the 20-year plan and those potentially affected by transportation improvements on the shortgrass prairie in Colorado's Eastern Plains. New alignments were precluded because the analysis and estimated mitigation area was based on a buffer of vegetation types around existing roads. Because any new alignments would occur in unknown territory, by definition the analysis was not able to accommodate them. Nevertheless, even the new Ports to Plains Interstate being contemplated to pass through the Eastern Plains—probably beyond the time frame of the 20-year plan—is anticipated to substantially use existing alignment.

If a species was known to use a given vegetative community for any part of its life cycle, the species was presumed present and affected; CDOT and FHWA would mitigate. The impact assessment treated all highway rights-of-way as habitat, regardless of quality or presence of individual species in any particular place, and irrespective of current maintenance practices such as mowing and spraying, which degrade the habitat. However, the parties realized that in many cases, most of the area where there would be an impact—which consisted of the entire right-of-way—would not be permanently affected by the CDOT–FHWA action, and in the case of projects exerting less of an impact, the area might not even be

Guidelines for Federal-Aid Participation in the Mitigation of Impacts to Upland Ecosystems and the Establishment of Ecological Mitigation Banks. That guidance supported

- Forming partnerships among levels of government and with nongovernmental stakeholders, including partnering with nonprofit resource management interests or agencies for land management and ownership,
- Establishing a preference for mitigation activities providing multispecies or ecosystem benefits, and
- Promoting use of existing authorities to perform advance mitigation.

The team also drew on *National Wildlife Federation v. Babbitt* (*11*), a particularly influential case decided in October 2000. Although that case overturned an incidental take permit issued by FWS, Judge David Levi's ruling upheld several key approaches used in the Shortgrass Prairie Initiative:

- A habitat approach to mitigation for listed and unlisted species;
- An across-the-board less than 1:1 mitigation ratio for all impacts regardless of quality (A half acre of mitigation per acre of impact ratio was developed in light of the knowledge that some of the affected areas would be highly degraded and conservation areas would be targeted for their high conservation value.);
- Targeting of mitigation dollars toward higher-quality and higher-priority conservation lands in the area under consideration,
- General assessments of the impacts of development on habitat rather than quantitative information on individual species members; and
- An understanding that use of "best available scientific and commercial data" under ESA does not require complete or "perfect data." [See discussion of this case point in *National Wildlife Federation v. Babbitt* and the accompanying notes (*11*).]

For the Shortgrass Prairie Initiative, FWS staff actively employed their prerogative to move the analysis and agreement forward using best available, that is, currently existing data, for an area that had relatively few comprehensive biological inventories, relative to other ecoregions. Use of best available data allowed the team to reach conclusions and move the project forward in a timely fashion, contributing greatly to the momentum and practicability of the project for all parties. The team also learned from weaker aspects of the subject of the case and planned to locate and fund all conservation parcels in advance of impacts, to increase certainty of implementation of the conservation measures.

Anticipating and Avoiding Reinitiation of ESA Section 7 Consultation

CDOT, FHWA, and FWS structured the scope of the analysis and the conservation area to anticipate and avoid the need for reinitiation of ESA Section 7 consultation, to the maximum extent possible, for the impacts of federal actions and transportation improvement projects on the existing roadway network over the next 20 years. (Such actions or projects include reconstruction, safety or capacity improvements, bridge improvements, or resurfacing.) As provided in the Code of Federal Regulations (50 C.F.R. 402.16), reinitiation of formal consultation is required if

1. The amount or extent of incidental take is exceeded,
2. New information reveals effects of the action that may affect listed species or critical habitat in a manner or to an extent not considered in the Biological Opinion,
3. The action is subsequently modified in a manner that causes an effect to the listed species or critical habitat not considered in the Biological Opinion, or
4. A new species listing or critical habitat designation occurs that may be affected by the action.

The agencies sought to avoid reinitiation of formal consultation in the following ways. With regard to the first point listed, the possibility of exceeding the amount or extent of incidental take was minimized by conducting the analysis planning for Section 7 compliance on the entirety of the state and federal highway systems in the Eastern Plains. Buffer distances were proposed and approved by statewide experts in each taxonomic group, leaving only the construction of new alignment that would add to the extent of incidental take. In the case of construction of new alignment, FHWA agreed to initiate site-specific consultation with FWS as necessary.

With regard to the second point, the partners sought to overestimate the manner and extent in which agency action could affect threatened, endangered, or candidate species and critical habitat, to compensate now, to the extent possible, for information that is currently unknown about subject species and habitats. The impact assessment treated all highway right-of-way as habitat, regardless of quality or presence of individual species in any particular place, and irrespective of current maintenance practices (e.g., mowing the entire right-of-way is standard practice). Furthermore, avoidance and minimization of impacts, as required by the ESA, was agreed to be accomplished through minimizing the project footprint (the extent of land affected by construction, e.g., run over by a construction vehicle or torn up) and through best management practices minimizing of direct and indirect impacts. CDOT, FHWA, and FWS agreed to work together to institute more beneficial practices and to incorporate the new information if subsequent information reveals that CDOT management practices can be improved to benefit or minimize harm to threatened, endangered, or candidate species.

With regard to the third point, because the initiative covers only ongoing activities on existing roads and no new road construction, the partners agreed that it is unlikely that the agency action will be modified to such a degree that any of the covered species will be affected in a manner or to an extent not anticipated in the CNHP–CDOT impact assessment. The partners were aware that planned transportation improvements will change as the Transportation Commission of Colorado considers needs and priorities over the next 20 years. However, by including the whole highway network and associated bridges, each species' range across the Eastern Plains, and areas of potential impact for each species in the impact assessment, they agreed that the federal action subject to Section 7 will likely not be modified except by the addition of new alignment, which would most likely require its own Section 7 consultation or reinitiation of the Section 7 consultation for such a project.

With regard to the last point, the partners noted that species could be listed or critical habitat could be designated in a way that their Memorandum of Agreement neither anticipates nor includes, and that initiation of Section 7 consultation could be required at the time of such listing. The initiative addresses a primary short list of species. CDOT and FHWA took the conservative approach of treating all vegetation and habitats associated with the included species as potential

The leading line of cases on the Section 7 "best available data" standard is in the Ninth Circuit. In contrast to the position that the Service must resolve uncertainties before making a decision under ESA Section 7(a)(2) or ESA Section 10(a)(2)(B)(iv), in *Connor v. Burford,* 848 F.2d 1441 (9th Cir. 1988), the Ninth Circuit held that "incomplete information about . . . activities does not excuse the failure to comply with the statutory requirement of a comprehensive biological opinion using the best information available." Accordingly, FWS said in its briefing for the Natomas case, "the Ninth Circuit's mandate in Conner was clear: in the face of uncertain or incomplete data, the Service must issue a comprehensive biological opinion based on the best information available at the time the decision is to be made." In response to NWF's charges of "improper speculation," FWS quoted the Ninth Circuit as "recognizing that the Service may be 'required to make projections . . . of the impact of [the agency action] on protected species.' 848 F.2d at 1454, citing *Roosevelt Campobello Int'l Park Comm'n,* 684 F.2d at 1052–55."

The standard set by the Ninth Circuit in *Greenpeace Action v. Franklin,* 14 F.3d 1324 (9th Cir. 1993), is this: "In fulfilling its duty [to avoid jeopardy], the agency 'shall use the best scientific and commercial data available' 16 U.S.C. § 1536(a)(2). When an agency relies on the analysis and opinion of experts and employs the best evidence available, the fact that the evidence is 'weak,' and thus not dispositive, does not render the agency's determination 'arbitrary and capricious.' Id. at 1336 (quoting Stop H-3 Assn. v. Dole, 740 F.2d 1442, 1460 (9th Cir. 1984) and citing Pyramid Lake Tribe of Indians, 898 F.2d at 1415)." With regard to the no jeopardy opinion at issue in Greenpeace Action, the Ninth Circuit concluded: "[w]hile the Service has repeatedly conceded that it was uncertain about the effectiveness of its management measures, it premised these measures on a reasonable evaluation of available data, not on pure speculation." Id. at 1337. Thus, FWS argued that it fulfilled its obligations under the ESA to make its (B)(iv) determination, based on the best available data, in light of acknowledged uncertainties.

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as for an actual PCC pavement that had undergone premature failure and early distress.

To conduct this study, an actual field site was needed. After a preliminary review of literature on early distress, it was decided to use pavements from US-20 near Fort Dodge, Iowa. This pavement, constructed in 1987, experienced premature failure and early distress. Numerous early distress or failure mechanisms have been hypothesized for US-20, including low initial air contents (either low in the mix or low after placement), high alkali contents in the mixes, alkali silica reaction, freeze-thaw damage, and the appearance of ettringite $[Ca_6Al_2(SO_4)_3(OH)_{12}.26H_2O]$ in air voids (*6–11*). The role of CFA, if any, in the failure is unknown. It was decided to collect a pavement slab and subgrade soils on a section of County Road P73, a feeder road to US-20 that crosses US-20 in a north–south direction, and which was placed at the same time as was US-20 by the same contractor using the same concrete mixture and materials. The County Road P73 section adjacent to US-20 had undergone the same early failure and early distress as had US-20, even though truck traffic was presumably a small fraction of that occurring on US- 20.

This paper reports on the comparison of the laboratory specimens that underwent accelerated aging to the slab samples from US-20 that underwent field aging. More detailed information can be found elsewhere (*12–17*).

MATERIALS AND METHODS

US-20 Slab Collection and Processing

Iowa County Road P73 is a north–south feeder road that intersects US-20 approximately 10 mi east of Fort Dodge, Iowa. As mentioned, it was constructed by the same contractor using the same job mix and materials as those used in the US-20 job. The actual section of County Road P73 that crosses US-20 from station 22155 + 36 to 22159 + 50 (126 m) was constructed on May 1, 1987.

On November 5, 1997, at an age of 3,841 days or approximately 10.5 years, a 1.2- × 1.8-m section of concrete pavement was removed from County Road P73. To minimize saw cutting, it was removed at the edge of the roadway at a cold joint. It was then transported to the University of New Hampshire (UNH) for sawing, coring, and subsequent analysis of bricks and cores for a variety of response variables (discussed later).

Mix Components, Mix Design, Mix Batching, and Molding

To be able to recreate the US-20 job mix, the mix design for the US-20 job was required, and the same materials used in the original mix were needed. The job mix was obtained from the Iowa Department of Transportation. The original materials that were used [portland cement, Class C coal fly ash (CFA-C), coarse aggregate, fine aggregate, air entrainment admixture, water reducing admixture] were identified and the suppliers were contacted. As much as possible, materials used for laboratory specimens were the same as or nearly the same as the materials used in the field pavement. Table 1 shows the relative proportions of the job mix.

The mixing was done in a 0.25-m^3 rotating steel drum mixer. Goals for slump and total air content were set for the properties of the freshly mixed concrete. Values of 3.5% total air and 50-mm slump were decided on and measured using ASTM C 231 and ASTM C 143,

TABLE 1 Batch Quantities for Laboratory Prisms Made with CFA-C

Batch	Red	Green	Yellow	Black
Cement	32.8 kg	32.8 kg	32.8 kg	32.8 kg
Fly Ash C	5.78 kg	5.78 kg	5.78 kg	5.78 kg
Water	18.73 kg	18.73 kg	18.73 kg	18.73 kg
Water reducer	37.74 ml	37.74 ml	37.74 ml	37.74 ml
Air entrainment	11.31 ml	11.31 ml	11.31 ml	11.31 ml
Coarse aggregate	112 kg	112 kg	112 kg	112 kg
Fine aggregate	92.1 kg	92.1 kg	92.1 kg	92.1 kg
Time of day	8:56 a.m.	10:03 a.m.	11:07 a.m.	11:57 a.m.
Day	3/10/98	3/10/98	3/10/98	3/10/98

respectively (*18*). Standard prism (7.62 × 7.62 × 29.94 cm) samples were cast, five samples to a mold. Fresh concrete was consolidated in two lifts with a 10-mm stainless steel rod. Surface finishes were prepared with hand trowels. Standard 10.16-cm diameter cylinders were also cast for compressive strength testing. Samples were cured in a fog room for 24 h at 98% relative humidity and 22 ± 2°C. After 24 h, the samples were stripped from their molds, stored in lime-saturated water, and transported to Cornell University, then UNH, and then the Cold Regions Research and Engineering Laboratory (CRREL) for accelerated aging treatments. All samples were subjected to the same transportation and conditions during transport regardless of required aging. The elapsed time for all the aging treatments was approximately 9 months.

Experimental Design

An experiment was designed to better understand how the three main aging variables, AA, CL, and FT, individually and collectively, influenced the physical and environmental response of the laboratory CFA-C prisms. By using various levels of aging for each main factor (AA, CL, FT), the influence of increased accelerated aging on physical and environmental performance could be examined. A $2^3 + 3$ full factorial design with center points was employed and allowed us to examine the effects of individual experimental variables as well as the interactions of two or three of the variables using an analysis of variance (ANOVA).

Aging Procedures

The first treatment the samples were subjected to was AA, performed at Cornell University. The subsequent treatments were CL, conducted at UNH, followed by FT, conducted at CRREL. The goal of the treatment scheme was to induce developmental and potentially degradative aging of the concrete on an accelerated time scale (on the order of months versus years) in a manner that approximated typical aging of concrete in a natural environment. AA was applied first to allow for the development of microstructure and then for potentially deleterious reactions under a developmental aging scenario. CL was applied second, to potentially produce stress microcracking (but not loss of physical specimen integrity). FT was applied third, to produce internal stresses due to freezing and thawing and potentially some loss of material integrity.

AA as Experimental Variable

Tanks were built to provide an accelerated aging environment for some of the specimens by curing at 60°C at high relative humidity

TABLE 2 Experimental Response Variables Measured in Laboratory Prism and Field Slab Samples

Method	Description	Reference
Compressive Strength	Examine the effects of the experimental design that resulted in a change in strength of the prisms. Compressive strength provides some indication of the physical integrity of the samples.	*18*
Microcracking	Assess the loss of monolith integrity in the samples as evidenced by damage that can be discerned through the use of neutron radiography.	*12, 13, 22*
Relative Dynamic Modulus	Assess the loss of monolith integrity through measurement of the relative dynamic modulus (RDM). The procedure measures compression or *p*-wave velocity through the prisms prior to and after freeze-thaw cycling. Decreases in RDM reflect damage and loss of integrity in the samples.	*18*
Uniformity Indicators	The uniformity indicator is derived from mercury intrusion porosimetry (MIP). It describes the relative shape of the two peaks (for larger and smaller pores) derived from the differential plot of the intrusion data. It is a general measure of the uniformity of pore sizes in the samples.	*12, 13, 15*
Porosity	The porosity is derived from MIP that gives the pore volume (in percent) of the samples.	*12, 13, 23*
Surface Area	The effective surface area is obtained from gas adsorption isotherms. It measures the surface area (m^2/g) within monolith samples.	*12, 13, 15*
Mineralogy	This variable is obtained through the use of X-ray powder diffraction (XRPD). The method can identify as well as quantify the concentration of crystalline minerals within the samples.	*12, 13, 16*
Alkalinity and Constituent Leaching as a Function of pH	The alkalinity is a measure of the buffer capacity of a sample. It can also be used to infer the chemical species providing the buffer (e.g., CO_3^{2-}). The constituent leaching as a function of pH gives a sense of the pH-dependent leaching behavior of elements of interest (e.g., Ca or Zn). Both are derived from a titration procedure on ground-up monolith samples.	*24*
pH-Stat Leaching	The equilibrium leaching of ground-up monolith samples at predetermined pH values of interest gives an indication of pH-dependent leaching behavior. This variable might reflect changes in the mineralogy in the experimental prisms as a result of the experimental design.	*24*
Geochemical Modeling	Data from pH-stat leaching are used in a geochemical thermodynamic equilibrium source code (MINTEQA2) to identify possible mineral phases that may control the equilibrium leaching of elements of interest (e.g., Cu, Cr) from ground-up prism monoliths.	*12, 13, 16*
Availability Leaching	This operationally defined leaching protocol uses a chelating agent ethylehediamine tetra-acetic acid (EDTA) to extract elements of interest (e.g., Ca, Pb) from ground-up monolith prism specimens. It is used to describe the amount of an element that would be available for leaching over a long time frame.	*25, 26, 27*
Leaching at Low Liquid-to-Solid Ratios	This operationally defined leaching protocol uses a reverse serial batch procedure to extract elements of interest (e.g., SO_4^{2-}, Cl) into leachates of increasing ionic strength. It can then be used to predict what monolith pore water constituent concentrations might be.	*24*
Cumulative Releases from Monoliths	This operationally defined protocol uses monolith tank leaching tests to look at the cumulative release (mg^2/m) of an element of interest (e.g., Cd, Ca) from the samples. Changes in mineralogy or changes in monolith integrity might change the release that is observed.	*24*
Tortuosity	Monolith tortuosity (τ) or matrix tortuosity reflects the tortuous diffusion pathway that a solute must travel to diffuse from the monolith. Tortuosity is perhaps the best measure to relate physical changes in monolith integrity (e.g., microcracking, MIP porosity) to changes in fluxes of constituents of interest that are leaching via diffusional processes from the slab and prism samples.	*27, 28, 29*
Observed Diffusion Coefficients from Monolith Leaching	This operationally defined protocol uses monolith tank leaching tests to look at the observed diffusion coefficient (D_{obs}, m^2/s) of an element of interest (e.g., Cd, Ca) from the experimental prisms.	*27, 28, 29*

Air Content

Air contents in the CFA-C mix during batching ranged from 2.9% to 4.1%, based on tests of air content in fresh concrete. Hardened concrete analyses of failed Iowa pavements suggested air voids of less than 2% to 6%.

Age

The equivalent age of the CFA-C prisms ranged from 1.0 to 2.9 years when age was estimated by compressive strength, 1.0 to 2.9 years when age was estimated by *p*-wave, and 1.1 to 4.8 years when age was estimated by nonevaporable water content. The actual chronological ages of the prisms were less than 2 months when accelerated aging began and about 7 months at the end of accelerated aging. Testing of the prisms began after about 9 months of elapsed time. The slab was about 10 years old when collected but had exhibited signs of early distress after about 3 years.

Compositional Differences

Si was the only element that showed differences in content between the CFA-C prisms and the slab. It was higher in the CFA-C prism mix (14% compared with 6.6%), and the source was the cement (data not shown).

TABLE 3 *(continued)* **Summary of Results Comparing CFA-C Laboratory Prisms with US-20 Slab Samples**

		Range of Values (Mean of Values)	
Category or Response Variable	**Units**	**Laboratory-aged CFA-C Prisms (from 2^3 +3 experimental design)**	**Field-aged US-20 Slab Samples**
CO_3^{2-} Controlling Solid (applicable pH range)	-	$CaCO_3$ (7-10), $CaMg(CO_3)_2$ (7-10)	$CaCO_3$ (7-12), $CaMg(CO_3)_2$ (7-12)
Cr Controlling Solid (applicable pH range)	-	None identified	None identified
Fe Controlling Solid (applicable pH range)	-	None identified	None identified
Mg Controlling Solid (applicable pH range)	-	$CaMg(CO_3)_2$ (5-10)	$CaMg(CO_3)_2$ (5-12)
Si Controlling Solid (applicable pH range)	-	SiO_2 (5-7)	SiO_2 (5-7)
SO_4^{2-} Controlling Solid (applicable pH range)	-	$BaSO_4$ (5-12), $Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26H_2O$ (10-12), $CaSO_4\cdot 2H_2O$ (7-10)	$BaSO_4$ (5-12), $CaSO_4\cdot 2H_2O$ (7-10)
Zn Controlling Solid (applicable pH range)	-	None identified	None identified
Cd Availability Leaching	mg/kg	1.9	3.1
Cu Availability Leaching	mg/kg	10.5	7.2 to 10.3
Ni Availability Leaching	mg/kg	31	7.8 to 155.3
Pb Availability Leaching	mg/kg	11.6	11.4 to 12
Zn Availability Leaching	mg/kg	31.3	13.2 to 14.4
Low Liquid-to-Solid (Pore Water) pH	pH	12.7 to 13	13.7
Pore Water Ionic Strength	molal	0.7 to 1.2	1.3
Na Monolith Cumulative Flux After 22 d (Release)	mg/m^2	1,270 to 2,850	2,490 to 3,395 (bulk) 8,430 (surface)
K Monolith Cumulative Flux After 22 d (Release)	mg/m^2	1,370 to 3,100	4,960 to 6,240 (bulk) 8,235 (surface)
Cl Monolith Cumulative Flux After 22 d (Release)	mg/m^2	Not quantifiable	615 to 665 (bulk) 4,685 (surface)
SO_4^{2-} Monolith Cumulative Flux After 22 d (Release)	mg/m^2	Not quantifiable	730 to 800 (bulk) 2,140 (surface)
Ca Monolith Cumulative Flux After 22 d (Release)	mg/m^2	16,990 to 27,520	23,270 to 25,200
Na Observed Diffusivity Through Binder ($D_{obs\,3}$)	m^2/s	1.1×10^{-12} to 6.2×10^{-12}	5.0×10^{-12} to 8.8×10^{-12} (bulk) 63.0×10^{-12} (surface)
K Observed Diffusivity Through Binder ($D_{obs\,3}$)	m^2/s	0.7×10^{-12} to 2.7×10^{-12}	6.1×10^{-12} to 15.0×10^{-12} (bulk) 25.0×10^{-12} (surface)
Cl Observed Diffusivity Through Binder ($D_{obs\,3}$)	m^2/s	1.5×10^{-11} to 2.6×10^{-11}	4.8×10^{-12} to 8.1×10^{-12} (bulk) 1.7 x 10-10 (surface)
Ca Observed Diffusivity Through Binder ($D_{obs\,3}$)	m^2/s	2.6×10^{-14} to 3.4×10^{-14}	2.5×10^{-14} to 3.1×10^{-14} (bulk) 0.7×10^{-14} (surface)
Tortuosity (τ_{MQ})	Unitless	30	30

NOTE: BDL = below detection limit.

Physical Integrity

Compressive strengths of the CFA-C prisms (after equating to cylinder cores) were shown to be similar to slab cores. The prisms ranged from 25.9 to 56.1 MPa (mean of 40.2). The slab samples ranged from 29.2 to 40.8 MPa (mean of 35.1). Some representative neutron radiographs and microcrack traces are shown in Figure 1. In the figure, note that the radiograph (left) detects locations in the thin section that are neutron-opaque because the microcrack is filled with a gadolinium-based stain. The microcrack cracks appear white. The images have been scanned with an optical scanner and the microcrack traces (right) have been digitized so that the microcrack extent (percentage area) can be quantified. Microcracking was not as extensive in the laboratory prisms as it was in the slab concrete. Typical percentages (microcrack trace pixel area/thin section pixel area) ranged from 0.3 to 2.8 (mean of 0.9) in the prisms and 0.3 to 6.6 (mean of 2.3) in the slab samples. The laboratory CFA-C mixture combined with high levels of heat aging resulted in differential pore size curves similar in nature to the slab concrete (Figure 2); both were a bimodal system of coarser and finer pore systems. Porosity values ranged from 8.2% to 10.2% (mean of 9.1) in the prism samples and 10.0% to 13.4% (mean of 11.7) in the slab samples. With respect to the coarser system of pores, the laboratory concretes exhibited smaller, more well-defined pore sizes. With respect to the finer system of pores, the CFA-C concrete treated

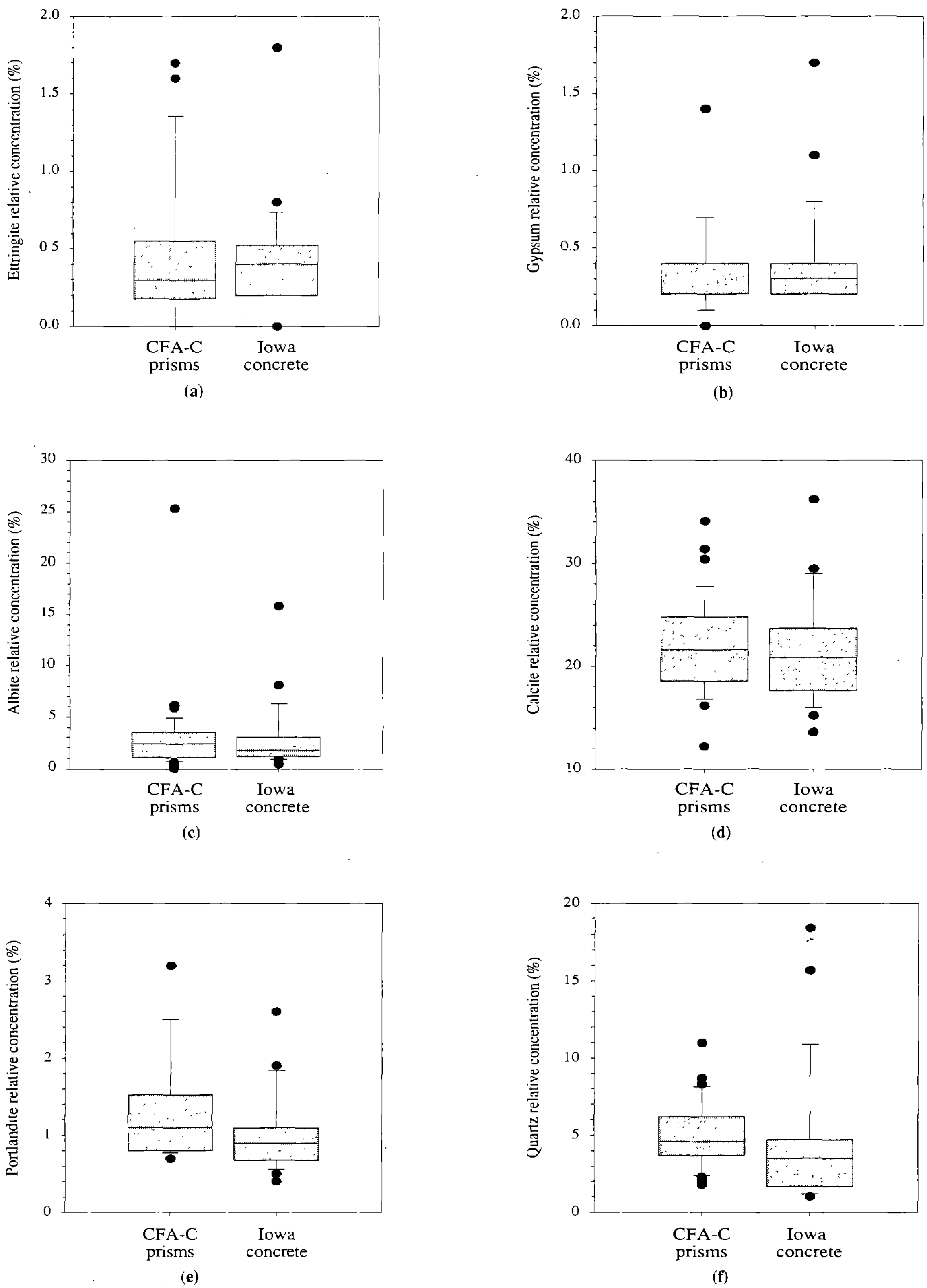

FIGURE 3 Box plots of laboratory prism and Iowa slab samples for selected mineral phases: (a) ettringite, (b) gypsum, (c) albite, (d) calcite, (e) portlandite, and (f) quartz.

ity. For both materials, only a fraction of Ni and Zn was available for leaching, whereas Cd, Pb, and Cu were completely available.

Low L/S Leaching

Although much greater Na and K concentrations were experimentally observed at low liquid-to-solid ratio (L/S) for the slab concrete sample, similar ionic strengths of the pore water were estimated for both the 28-day-cured CFA-C sample and the slab concrete sample. A much lower ionic strength of the pore water was estimated for the high AA aged CFA-C sample than for the slab concrete (0.7 to 1.2 molal versus 1.3 molal). The pH values of the pore waters were similar, about 13.

Monolithic Leaching

Comparison of the results obtained from mass transfer leaching tests carried out on the slab concrete samples and the CFA-C mix samples showed a much greater Na, K, and Cl release and a much lower release of Ca (Figure 6) for the slab samples compared with the CFA-C prism samples. The high Cl fluxes seen, especially from the slab surface specimens, may be related to road salting. Release modeling showed significant differences in Na, K, and Cl observed diffusivities between the slab concrete samples and the CFA-C samples; greater Na and K observed diffusivities and lower Cl observed diffusivities were seen for the slab samples. However, no significant difference in Ca observed diffusivities could be observed between the slab and prism samples. The slab surface specimens exhibited more pronounced differences than the prism samples. The observed higher level of microcracking in the surface portions of the slab in the slab concrete may help to explain this. Bulk tortuosities were found to be similar between the two materials.

CONCLUSIONS

An accelerated aging protocol was developed to look at the individual and interactive effects of one developmental and two degradative aging methods on the physical and environmental performance of PCC made with CFA. The aging protocol had an impact on both physical and chemical properties of the specimens. Generally, the main effects of the aging methods were more important than the interactive effects, which was unexpected.

The range and measure of central tendency for most response variables from the aged laboratory prisms and the field samples overlapped or were similar, suggesting that the accelerated aging method did a reasonable job of producing a pavement of similar age and distress to the field pavement. The use of both physical and environmental response variables shows the linkage between such variables as compressive strength, microcracking, fine pore structure, Cl diffusive leaching (an efflux related to road salting that increases the concentration of Cl in the monolith) and Ca diffusive leaching (related to change in matrix structure and loss of Ca).

Comparisons with earlier accelerated aging methods for bituminous asphaltic pavements are useful (*30, 31*). In hydrophobic materials with little chemical reactivity, loss of tortuosity dramatically affects the diffusive leaching behavior of many constituents of concern contained in recycled materials. In PCC, the matrix is hydrophilic and contains a much more elaborate fine pore structure, and the matrix is chemically reactive (e.g., sorption, acid-base reactions, and exchange reactions can occur). Despite significant aging, the matrix may still be able to control contaminant release, regardless of their source.

These results hold promise for the further refinement of an accelerated aging protocol for PCC. Unlike hydrophilic asphaltic pavements (*22, 23*), the loss of pavement integrity in PCC through degradative aging mechanisms may be less important than developmental aging reactions in affecting potential release. For PCC materials, AA may

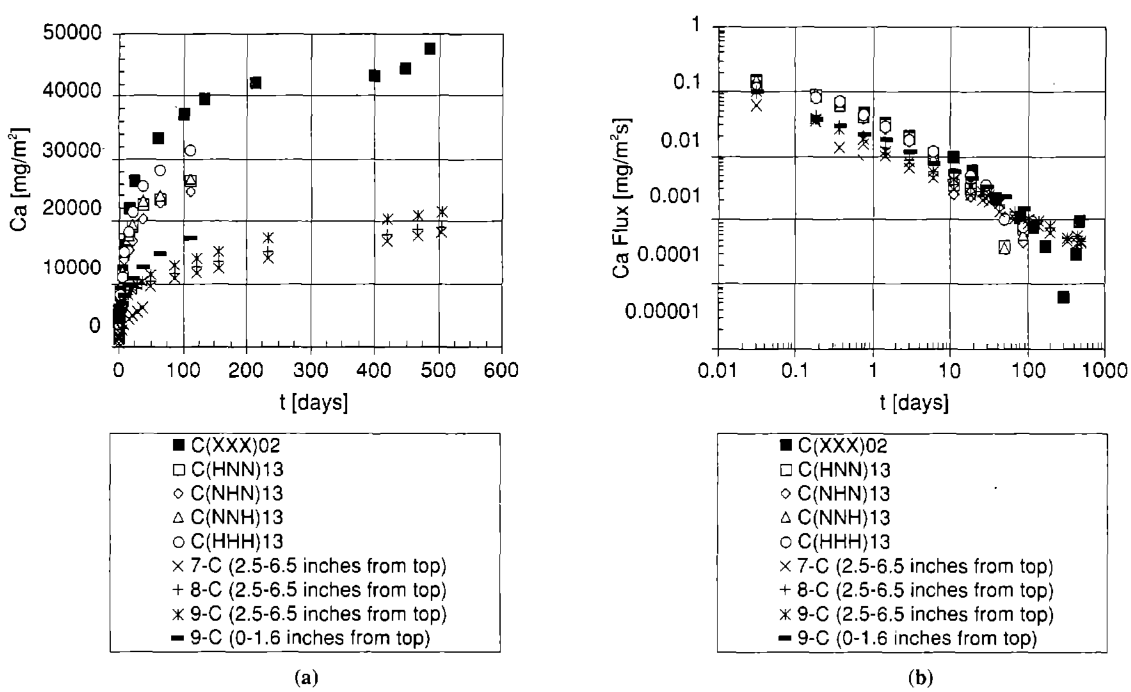

FIGURE 6 Ca release from monolithic laboratory and slab samples: (*a*) cumulative mass released in mg/m² and (*b*) flux released in mg/m²s (NOTE: closed symbols = aged laboratory prism samples; △ = US-20 slab samples and their locations with depth in slab).

TRANSPORTATION RESEARCH RECORD: JOURNAL OF THE TRANSPORTATION RESEARCH BOARD

Peer Review Process

The *Transportation Research Record: Journal of the Transportation Research Board* publishes approximately one-third of the nearly 2,000 papers that are peer reviewed each year. The mission of the Transportation Research Board (TRB) is to disseminate research results to the transportation community. The *Record* series contains applied and theoretical research results as well as papers on research implementation.

The TRB peer review process for the publication of papers allows a minimum of 30 days for initial review and 60 days for rereview, to ensure that only the highest-quality papers are published. At least three reviews must support a committee's recommendation for publication. The process also allows for scholarly discussion of any paper scheduled for publication, along with an author-prepared closure.

The basic elements of the rigorous peer review of papers submitted to TRB for publication are described below.

Paper Submittal: May 1–August 1

Papers may be submitted to TRB at any time. However, most authors use the TRB web-based electronic submission process available between May 1 and August 1, for publication in the following year's *Record* series.

Initial Review: August 15–September 15

TRB staff assigns each paper by technical content to a committee that administers the peer review. The committee chair assigns at least three knowledgeable reviewers to each paper. The initial review is completed by mid-September.

Chair Actions: September 15–October 15

By October 1, committee chairs make a preliminary recommendation, placing each paper in one of the following categories:

1. Publish as submitted or with minor revisions;
2. Publish pending author changes and rereview; or
3. Reject for publication.

By mid-October, committee chairs communicate the results of the initial review to the corresponding author indicated on the paper submission form. Corresponding authors communicate the information to coauthors. Authors of papers in Category 2 (above) must submit to the committee chair a revised version addressing all reviewer comments and must include a cover letter explaining how the concerns have been addressed.

Rereview: November 20–January 25

The committee chair reviews revised papers in Category 1 (above) to ensure that the changes are made and sends the Category 2 revised papers to the initial reviewers for rereview. After rereview, the chairs make the final recommendation on papers in Categories 1 and 2. If the paper has been revised to the committee's satisfaction, the chair will recommend publication. The chair communicates the results of the rereview to the authors.

Discussion: February 1–May 1

After the Annual Meeting, discussions may be submitted for papers that will be published. TRB policy is to publish the paper, the discussion, and the author's closure in the same *Record*.

Attendees interested in submitting a discussion of any paper presented at the Annual Meeting must notify TRB no later than February 1. If the paper has been recommended for publication, the discussion must be submitted to TRB no later than March 1. A copy of this communication is sent to the author and the committee chair.

The committee chair reviews the discussion for appropriateness and asks the author to prepare a closure to be submitted to TRB by April 1. The committee chair reviews the closure for appropriateness. After the committee chair approves both discussion and closure, the paper, the discussion, and the closure are included for publication together in the same *Record*.

Final Manuscript Submittal: April 1

In early February, TRB requests a final manuscript for publication—to be submitted by April 1—or informs the author that the paper has not been accepted for publication. All accepted papers are published by December 31.

Paper Awards: April to January

The TRB Executive Committee has authorized annual awards sponsored by the Technical Activities Division (Division A) Group Councils for outstanding published papers:

- Pyke Johnson Award (Group 1: Transportation Systems Planning and Administration);
- K. B. Woods Award (Group 2: Design and Construction of Transportation Facilities);
- D. Grant Mickle Award (Group 3: Operation, Safety, and Maintenance of Transportation Facilities); and
- John C. Vance Award (Group 4: Legal Resources).

Published papers sponsored by Group 5: Intergroup Resources and Issues may be considered for any of the awards above, as appropriate. Each Group also may present a Fred Burggraf Award to authors 35 years of age or younger.

Peer reviewers are asked to identify papers worthy of award consideration. Each council reviews all papers nominated for awards and makes a recommendation to TRB by September 1. All nominated papers are reviewed by the Division A Council for suitability. TRB notifies winners of the awards, which are presented at the following Annual Meeting.

Annual Meeting

The majority of papers are submitted to TRB for both publication and presentation. Chairs of committees that review papers for publication also make recommendations on presentations. After completion of the initial review, in addition to making the preliminary publication recommendations, chairs make presentation recommendations. This ensures high-quality paper sessions at the Annual Meeting. Authors of all papers on the program are asked to submit the revised versions of their papers electronically for a CD-ROM distributed at the Annual Meeting.

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